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SUMMARY OF MECHANICAL PROPERTIES OF LAC DU BONNET AND EYE-DASHWA SPECIMENS

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INTRODUCTION

A major part of the Nuclear Fuel Waste Management Project is the compilation of a generic data base of the mechanical and thermal-mechanical properties of rock types under consideration for a possible waste repository. Towards this end, measurements have been conducted at MRL and other laboratories on granitic formations located at the underground research laboratory (URL), Whiteshell (WN), and Atikokan (ATK) sites. These measurements include;

i. uniaxial compression tests
ii. Brazilian tensile tests
iii. dilatational velocity measurements
iv. high temperature and pressure triaxial tests

One hundred and sixty two samples have been tested uniaxially. These included 78 from URL, 34 from WN and 50 from ATK. One hundred and thirty-nine samples have undergone triaxial testing, with a total of 80 tests conducted under ambient temperature conditions, 28 at 100°C, and 31 at 200°C. The purpose of this report is to present a summary of these data and some statistical analyses. Where possible and practical, some mechanical properties have been plotted against both vertical depth and elevation.

SAMPLE DESCRIPTION

Specimens used for the investigations were from either standard engineering samples (those representative of the borehole lithology), or extended engineering samples (obtained from areas of specific interest such as proposed operating levels of the URL).

Generally, samples from the URL site outside Lac du Bonnet, Manitoba were grey to pink granite, medium to coarse grained, with approximate compositions of 30% K-feldspar, 30% plagioclase, 30% or slightly less quartz, and 10% or slightly more mafic minerals (mainly biotite), (1).

Samples from the WN boreholes located at the Whiteshell Nuclear Research site near Pinawa, Manitoba, were composed of approximately 24% to 31% K-feldspar, 25% quartz, 36 to 45% plagioclase, and 2% biotite (2,3). Both the URL and WN boreholes are located in the Lac Du Bonnet pluton.

ATK specimens were obtained from the Eye-Dashwa Lake pluton near Atikokan, Ontario and contained approximately 25% quartz, 23% K-feldspar, 43% plagioclase, 1% hornblende, 4% biotite, 1% epidote, and 3% others, (4,5). There were no visible cracks in any of the core specimens tested.

METHODOLOGY

UNIAXIAL COMPRESSION MEASUREMENTS

The reader is referred to Technical Data 303410-M01/78 (6). The two Phillips PR 9302 strain bridges and the Mosely Autograph 2FRA X-Y recorder referred to in that document were replaced, in the present study, by two Bruel and Kjaer Type 1526 strain indicators and a Hewlett Packard 7046B X-Y recorder. These equipment were used to measure and record the axial and transverse strains as a function of axial load.

HIGH TEMPERATURE AND PRESSURE TRIAXIAL MEASUREMENTS

The triaxial investigations involve a series of tests which were carried out over a period of time. The methodology used during the different triaxial test series has undergone some refinement since the inception of the program. The initial test procedure and subsequent modifications which are described in CANMET Division Reports ERP/MRL 80-102(TR) (7) and ERP/MRL 82-11(TR) (8), were used to test the WN and ATK specimens. URL specimens were tested using the procedure outlined in CANMET Division Report ERP/MRL 84-22(TR), (9).

BRAZILIAN TENSILE STRENGTH AND COMPRESSIONAL WAVE VELOCITY MEASUREMENTS

Both procedures are described in CANMET Division Report 79-60(TR) (10).

DATA SUMMARY

Table 1 provides a summary of the vertical depth, elevation and mechanical properties of the uniaxial specimens from the WN, URL and ATK sites. Tables 2 and 3 show vertical depth and elevation above sea level interval data, respectively, for the WN and URL mechanical properties. Unless otherwise noted, each interval was chosen to include eight data points. Table 4 offers similar interval data for the ATK specimens (ATK intervals were chosen to include 5 test results). The test results on the ATK specimens were not reduced to mean sea level elevation due to the lack of collar elevation data.

Table 5 summarizes the statistical analyses of the mechanical properties data. Included in the analyses were sample populations from Lac du Bonnet (URL, WN), Eye-Dashwa Lake (ATK), and the combined data from both sites.

Table 6 summarizes the triaxial results of all specimens. For the purpose of comparison, Mohr Coulomb analyses were conducted using the mean triaxial strengths determined for the sample populations outlined in Table 5. Tables 7, 8 and 9 summarize the results of the analyses utilizing data from both plutons for the temperature ranges of 21°C, 100°C and 200°C, respectively. Tables 10, 11 and 12 show the results of the analyses based only on data from the URL and WN sites (i.e. from the Lac du Bonnet pluton). Results of the Mohr Coulomb analyses for the ATK specimens are presented in Tables 13, 14 and 15. Failure envelopes were generated using the empirical failure criterion developed by Hoek and Brown (12).

Tables 16 and 17 summarize the triaxial strengths and tangent modulus of elasticity for the various confining pressure and temperature test configurations. Brazilian tensile results are presented in Table 18.

Figures 1, 2, 3 and 4 show the Lac du Bonnet vertical depth profiles and Figures 5, 6, 7 and 8 the elevation above sea level profiles of the tangent modulus of elasticity, zero pressure compressional wave velocity, uniaxial compressive strength and Poisson's ratio, respectively for the Lac du Bonnet results. The vertical depth profiles for specimens obtained from Atikokan are provided in Figs. 9, 10, 11 and 12.

Figures 13, 14 and 15 show the Mohr's circle and strength envelopes made using the aggregate results for samples from both plutons for the 21°C, 100°C and 200°C test series, respectively. Figures 16, 17 and 18 represent the Mohr Coulomb diagrams for samples from the Lac du Bonnet pluton at the 21°, 100°, and 200°C temperature ranges. The Mohr Coulomb diagrams for the Atikokan specimens are presented in Figs. 19, 20 and 21.

Figures 22 and 23 show the effects of confining pressure and temperature, respectively on the aggregate mean triaxial strength. Also, presented in Figs. 24 and 25 respectively, are the effects of confining pressure and temperature on the tangent modulus of elasticity

The cohesion and internal friction angles determined from the Mohr Coulomb analyses are plotted against temperature in Figs. 26 and 27, respectively.

DISCUSSION

UNIAXIAL MECHANICAL PROPERTIES

One hundred and sixty two granitic samples originating from the URL, WN and ATK boreholes have been tested uniaxially. These yielded a mean uniaxial compressive strength of 195 MPa, a mean density of 2.64 g/cc, a mean Young's modulus of 67.6 GPa, a mean Poisson's ratio of 0.27, and a mean zero pressure velocity of 4.26 km/sec.

As indicated in Table 5, the Atikokan samples are stronger than those from the Lac du Bonnet batholith. The mean uniaxial compressive strength and Young's modulus values for the Lac du Bonnet samples were 212 MPa and 73.9 GPa, respectively. In comparison, the mean uniaxial compressive strength and Young's modulus values for the Lac du Bonnet formation were 187 MPa and 64.7 GPa, respectively. The mean zero pressure compressional wave velocity value, was higher for the Atikokan samples (4.53 km/s) as compared to the Lac du Bonnet samples (4.17 km/s).

There was a very good agreement between density and Poisson's ratio values for samples from the two rock formations. A mean density value of 2.65 gm/cc was observed for the Lac du Bonnet samples. This compares with 2.64 gm/cc for the Eye Dashwa Lakes samples. The mean Poisson's ratio of the Lac du Bonnet formation was 0.26. This compares with 0.27 for the Eye Dashwa Lakes samples.

While no Brazilian tests were conducted on ATK specimens, seventy-two tests performed on URL and WN samples indicated a mean tensile strength of 9.49 MPa.

When one examines the variation in mechanical properties with depth, the two sample populations exhibit considerably different behaviour. Figure 1 shows a definite trend toward decreasing tangent modulus of elasticity with depth for the Lac du Bonnet results. Mean results of samples obtained from the ATK site exhibited a decrease in modulus with depth to approximately 550 m at which point it seems to stabilize, (Fig. 9).

The mean zero pressure compressional wave velocity (Fig. 2) and uniaxial compressive strength (Fig. 3) also decreased significantly with depth for the Lac du Bonnet samples. While there are some similarities in behaviour between the two formations the trends are not nearly so pronounced for the Atikokan samples.

The Poisson's ratio showed little variation with depth for both sites, (Figs. 4 and 12).

As might be expected, the elevation profiles plotted using the Lac du Bonnet results bear a close resemblence to the vertical depth profiles, (Figs. 5, 6, 7 and 8).

TRIAXIAL MECHANICAL PROPERTIES

The effects of confining pressure and temperature on the mechanical properties of samples from the Lac du Bonnet and Eye-Dashwa plutons have been described at length elsewhere (7,8,9,11). As a result, only the generalized effects of temperature and constraint on the mechanical properties will be discussed here.

Triaxial Strength

Figure 22 indicates that the mean strength increase with increasing confining pressure was very consistent for the three temperature ranges. There was an average increase of 151 MPa as the confining pressure increased from 3.5 to 17.0 MPa, and 122 MPa from 17.0 to 35.0 MPa.

While the mean triaxial strength decreased with increasing temperature for all confining pressures, the greatest effect was observed on heating from 100°C to 200°C. At a confining pressure of 3.5 MPa, a small decrease in strength of 6 MPa was noted as the temperature increased from 21°C to 100°C, while subsequent heating to 200°C resulted in a considerably larger decrease of 28 MPa. Decreases in the mean strength of 16 and 36 MPa, respectively, were observed over the same temperature ranges at a confining pressure of 17 MPa. At 35.0 MPa, the degree of strength decrease was far more consistent; a 24 MPa reduction in strength was noted as the temperature was increased from 21°C to 100°C and 27 MPa from 100°C to 200°C, (Fig. 20).

Tangent Modulus of Elasticity

The three temperature ranges showed considerable variation in tangent modulus of elasticity at a confining pressure of 3.5 MPa (Fig. 21). Values ranged from a high of 72.08 GPa for tests conducted at 100°C to a low of 50.84 GPa at 200°C. Moduli values determined at 21°C remained relatively insensitive to increasing confining pressure, varying only slightly from an average value of 66.50 GPa. The tests at one hundred degrees exhibited a considerable drop in modulus (6.31 GPa) as the confining pressure was increased

from 3.5 to 17.0 MPa. There was, however, only a slight increase in modulus value to 66.39 GPa as the confining pressure was raised to 35.0 MPa. At 200°C, the moduli increased by 6.31 GPa as the confining pressure was increased from 3.5 to 17.0 MPa and 4.42 GPa from 17.0 to 35.0 MPa. It is interesting to note that there seems to be a tendency for the moduli of all the temperature ranges to converge to some value around 65 MPa as the confining pressure increases.

Measurements taken at confining pressures of 17.0 and 35.0 MPa showed a decreasing modulus with increasing temperature with the largest decrease occurring between temperature ranges of 100°C and 200°C. At 3.5 MPa, however, a considerable increase in tangent modulus was noted from ambient to 100°C (64.73 to 72.08 GPa) while subsequent heating to 200°C resulted in the lowest mean modulus observed for any test configuration (50.84 GPa), (Fig. 22).

Cohesive Strength

The cohesive strength appeared to be relatively insensitive to increasing temperature at a confining pressure of 3.5 MPa (Fig. 23), increasing by only 1 MPa after heating to 200°C. The cohesion determined for samples tested at a confining pressure of 17.0 MPa increased by 4 MPa when heated from 21°C to 100°C, and dropped by 7 MPa on further heating to 200°C (43 to 47 to 40 MPa). Measurements conducted at a confining pressure of 35.0 MPa indicated that the cohesion decreased steadily with increasing temperature dropping from 75 MPa to 64 MPa on heating from 21°C to 200°C.

Angle of Internal Friction

The angle of internal friction measured at a confining pressure of 3.5 MPa remained unchanged at 62° as the temperature was increased from 21°C to 100°C, but dropped by 4° on subsequent heating to 200°C (Fig. 24). Values observed at 17.0 MPa confining pressure, however, showed the internal friction angle decreasing by 2° when heated from 21°C to 100°C (56° to 54°) and then remaining constant to 200°C. Increasing temperature had no apparent effect on the friction angle at a confining pressure of 35.0 MPa which remained constant at 46° throughout the heating cycle.

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Table 1 - Vertical depth, elevation and uniaxial mechanical properties of URL, WN and ATK specimens

Specimen No.		Vertical depth (m)	Elevation (m)	Young's modulus (GPa)	Poisson's ratio	Uniaxial compressive strength (MPa)	Zero pressure velocity (km/sec)	Dynamic young's Modulus (GPa)	Density (gm/cc)
URL B9	0.00	0.00	N/A	64.4	0.28	183	4.34	38.5	2.61
URL B10	0.15	0.15	N/A	53.6	0.29	177	4.42	44.1	2.62
URL B9	3.90	3.90	N/A	65.2	0.26	134	5.32	60.7	2.63
URL B9	14.46	14.46	N/A	64.9	0.29	191	5.48	60.2	2.62
URL 5	16.40	16.17	271.56	73.0	0.27	219	5.07	53.9	2.62
WN 2	24.75	23.9	244.5	70.0	0.23	233	4.9	54.5	2.63
URL 1	46.40	45.84	246.54	77.1	0.24	229	5.67	72.0	2.65
WN 2	55.45	53.5	214.9	74.0	0.23	173	5.1	61.2	2.73
URL 1	68.50	66.36	226.02	82.2	0.25	186	6.06	81.1	2.65
URL 5	76.90	74.69	213.04	73.0	0.22	230	5.67	74.6	2.65
WN 2	85.40	82.2	186.2	73	0.21	159	5.4	71.2	2.75
WN 2	98.50	94.7	173.7	69	0.21	232	5.1	61.2	2.65
URL 1	107.40	100.60	191.78	86.0	0.29	248	5.68	66.2	2.69
URL 5	108.30	104.60	183.13	72.5	0.38	199	5.14	36.6	2.59
WN 2	124.70	119.8	148.6	69	0.21	235	4.7	51.6	2.63
URL 5	126.60	122.66	165.07	70.4	0.18	175	5.04	61.9	2.64
URL 5	128.00	124.05	163.68	71.4	0.29	196	4.87	47.6	2.63
URL 5	133.00	128.81	158.92	80.0	0.30	221	5.44	58.0	2.64
URL 7	135.47	130.85	154.83	71.6	0.23	227	5.42	66.6	2.63
URL 7	138.46	133.74	151.94	70.2	0.27	209	5.68	68.3	2.64
WN 1	138.60	133.9	134.6	69	0.26	213	4.8	49.7	2.64
URL 5	138.63	134.44	153.29	69.9	0.32	189	4.79	42.0	2.62
URL 7	143.27	138.39	147.29	68.7	0.24	181	5.68	70.2	2.64
WN 2	145.85	140.0	128.4	71	0.21	224	4.5	47.5	2.64
URL 7	155.86	150.55	135.13	70.4	0.22	219	5.68	74.4	2.64
URL 5	157.20	152.76	134.97	71.4	0.26	180	4.97	52.3	2.59
WN 1	160.90	155.3	113.2	66	0.29	191	4.7	44.5	2.64
URl 7	170.70	164.88	120.80	65.4	0.22	201	5.27	64.0	2.63
URL 1	177.10	170.37	122.01	83.4	0.27	200	5.18	56.0	2.61
URL 1	177.40	170.67	121.71	69.7	0.25	184	4.90	52.6	2.63
URL 7	181.80	175.61	110.07	65.4	0.25	183	4.81	50.9	2.64

Table 1 (Cont'd)

Specimen No.		Vertical depth (m)	Elevation (m)	Young's modulus (GPa)	Poisson's ratio	Uniaxial compressive strength (MPa)	Zero pressure velocity (km/sec)	Dynamic young's Modulus (GPa)	Density (gm/cc)
URL 1	184.68	177.95	114.43	70.9	0.27	192	5.06	53.8	2.62
URL 7	184.70	178.41	107.27	65.4	0.24	180	4.83	52.0	2.63
URL 1	191.38	184.65	107.73	71.4	0.25	176	5.17	58.5	2.62
URL 7	192.90	186.33	99.35	67.3	0.26	234	4.91	39.5	2.63
URL 7	197.86	191.12	94.56	67.2	0.27	221	4.74	47.5	2.64
URL 5	199.10	192.87	94.86	73.5	0.30	191	5.09	50.7	2.63
WN 1	224.00	215.7	52.8	72	0.30	210	4.8	45.2	2.64
URL 1	230.50	221.12	71.26	84.9	0.23	189	5.26	62.3	2.61
WN 1	246.00	236.7	31.8	71	0.20	219	4.7	52.3	2.63
URL 5	246.50	238.45	49.28	69.0	0.25	226	5.45	65.0	2.63
URL 1	254.30	244.92	47.46	75.0	0.26	197	4.51	43.6	2.62
URL 2	256.00	247.06	33.85	64.9	0.25	203	3.84	32.3	2.63
URL 5	274.51	265.89	21.84	58.1	0.22	179	4.03	37.6	2.64
URL 5	277.59	268.95	18.78	64.9	0.26	193	3.95	33.3	2.62
UR1 5	281.63	271.71	16.02	61.4	0.28	191	4.08	34.1	2.62
URL 1	282.68	272.35	20.03	70.9	0.19	203	4.57	50.1	2.63
UR1 5	289.70	279.78	7.95	66.2	0.24	197	4.07	36.9	2.63
URL 1	292.90	280.53	11.85	65.8	0.22	160	4.85	54.6	2.65
WN 1	294.50	282.8	-14.3	71	0.27	205	4.8	48.7	2.64
URL 1	299.90	287.53	4.85	65.8	0.24	177	4.51	45.2	2.62
URL 1	302.40	290.03	2.35	74.5	0.25	208	4.74	49.2	2.63
WN 1	303.50	291.3	-22.8	67	0.24	224	4.7	49.3	2.63
URL 5	334.00	322.24	-34.51	58.8	0.25	129	4.40	43.2	2.65
WN 1	345.50	330.9	-62.4	70	0.24	227	4.8	51.4	2.63
URL 5	370.00	357.45	-69.72	56.2	0.25	176	3.77	31.2	2.63
WN 1	384.80	367.7	-99.2	69	0.29	219	4.9	48.7	2.66
URL 6	373.80	373.80	-83.72	59.2	0.39	181	3.73	18.4	2.63
URL 6	374.70	374.70	-84.62	61.7	0.31	170	3.84	28.0	2.63
URL 6	374.98	374.98	-84.90	58.5	0.33	204	3.76	25.1	2.63
URL 1	397.80	397.80	-87.42	61.4	0.26	155	4.32	40.6	2.66
WN 4	409.00	387.7	-120.9	67.8	0.21	211	4.41	45.8	2.65

Table 1 (Cont'd)

Specimen No.		Vertical depth (m)	Elevation (m)	Young's modulus (GPa)	Poisson's ratio	Uniaxial compressive strength (MPa)	Zero pressure velocity (km/sec)	Dynamic young's Modulus (GPa)	Density (gm/cc)
URL 6	391.38	391.38	-101.30	55.5	0.32	197	3.71	25.3	2.63
URL 6	391.61	391.61	-101.53	56.6	0.29	170	3.55	25.5	2.65
WN 1	410.70	391.8	-123.3	73	0.22	231	4.8	53.1	2.63
URL 6	391.89	391.89	-101.81	56.4	0.31	183	3.73	26.4	2.63
URL 6	392.17	392.17	-102.69	58.2	0.30	145	3.47	23.2	2.60
URL 1	443.20	422.68	-130.30	68.6	0.30	146	2.87	16.0	2.61
URL 5	441.75	426.04	-138.31	56.1	0.31	227	3.70	26.2	2.66
URL 5	441.98	426.26	-138.53	52.9	0.30	186	3.57	25.2	2.66
URL 5	442.26	426.53	-138.80	56.7	0.27	224	3.64	28.1	2.65
URL 5	442.54	426.80	-139.07	56.6	0.29	200	3.83	29.7	2.65
URL 2	448.10	430.32	-149.41	53.5	0.22	179	3.70	31.8	2.64
URL 5	450.90	434.86	-147.13	54.0	0.36	163	3.48	19.1	2.65
WN 1	460.60	438.2	-169.7	64	0.24	214	4.3	41.3	2.63
WN 4	469.25	445.3	-176.5	66.1	0.23	169	4.12	38.8	2.65
WN 4	482.30	457.1	-188.3	68.5	0.23	182	3.62	30.0	2.65
URL 1	496.70	472.74	-179.76	64.6	0.31	154	3.47	22.9	2.64
WN 4	505.57	478.2	-209.4	74.9	0.20	217	3.96	37.3	2.64
URL 5	496.80	478.95	-191.22	53.1	0.27	186	3.52	26.3	2.63
URL 1	527.40	501.14	-208.76	66.4	0.32	180	3.57	23.5	2.64
WN 4	551.45	519.5	-250.7	71.4	0.25	166	3.91	33.8	2.65
WN 4	564.40	531.0	-262.2	78.7	0.25	192	3.78	31.7	2.66
URL 2	586.00	559.82	-278.91	52.6	0.26	181	3.16	21.4	2.62
URL 1	592.60	561.46	-269.00	64.4	0.30	167	3.38	22.4	2.64
WN 4	603.60	565.6	-296.80	72.1	0.28	168	3.90	31.5	2.65
URL 1	615.90	582.69	-290.31	62.4	0.32	181	3.75	26.0	2.65
WN 4	631.70	590.2	-321.4	27.4	0.22	95	3.45	27.5	2.64
WN 4	660.30	614.8	-346.0	69.7	0.25	165	3.56	28.0	2.65
URL 1	662.40	635.67	-343.29	63.6	0.36	166	3.61	20.6	2.66
WN 4	692.70	642.4	-373.6	68.9	0.27	168	3.69	28.8	2.64
WN 4	719.10	664.4	-395.6	68.6	0.23	158	3.36	25.7	2.64
URL 2	705.70	668.89	-387.98	56.2	0.22	152	3.49	27.7	2.63

Table 1 (Cont'd)

Specimen No.		Vertical depth (m)	Elevation (m)	Young's modulus (GPa)	Poisson's ratio	Uniaxial compressive strength (MPa)	Zero pressure velocity (km/sec)	Dynamic young's Modulus (GPa)	Density (gm/cc)
WN 4	747.20	687.8	-419.0	64.4	0.34	181	2.96	15.1	2.66
WN 4	789.90	722.8	-454.0	60.7	0.32	155	3.20	19.0	2.65
WN 4	809.70	738.7	-469.9	56.5	0.26	166	2.60	14.7	2.66
URL 2	798.60	752.73	-471.82	58.5	0.13	158	3.66	34.0	2.64
WN 4	841.10	763.5	-494.7	62.9	0.25	171	2.63	15.3	2.65
WN 4	863.60	781.1	-512.3	59.1	0.39	147	2.89	11.0	2.62
WN 4	906.80	813.9	-545.1	63.8	0.34	165	2.47	10.5	2.65
URL 2	871.50	815.63	-534.72	53.8	0.28	163	3.43	24.2	2.63
WN 4	928.30	829.7	-560.9	59.4	0.27	151	2.50	13.3	2.65
URL 2	1001.20	929.83	-648.92	51.0	0.24	156	2.81	17.6	2.63
URL 2	1080.32	990.98	-710.07	51.6	0.30	198	2.53	12.4	2.62
URL 2	1080.55	991.19	-710.28	51.8	0.22	190	2.45	13.8	2.63
URL 2	1080.83	991.45	-710.54	51.9	0.40	163	2.52	7.8	2.63
URL 2	1081.06	991.66	-710.75	52.5	0.30	166	2.48	12.0	2.63
URL 2	1081.67	992.22	-711.31	54.3	0.34	178	2.62	11.7	2.63
URL 2	1081.90	992.43	-711.52	51.8	0.36	162	2.86	13.0	2.63
URL 2	1082.21	992.71	-711.80	52.0	0.43	160	2.88	7.7	2.63
URL 2	1082.44	992.92	-712.01	46.6	0.35	180	2.71	12.0	2.62
URL 2	1094.80	1004.26	-723.29	55.9	0.30	172	2.91	16.5	2.63
ATK 1	13.40	12	N/A	123.4	0.39	219	5.70	43.16	2.65
ATK 1	40.10	38	N/A	82.4	0.24	221	5.25	61.97	2.65
ATK 1	79.50	79	N/A	87.9	0.28	228	5.36	59.33	2.64
ATK 1	94.60	94	N/A	82.4	0.24	185	5.30	62.68	2.63
ATK 5	106.50	103	N/A	96.2	0.33	242	4.76	40.68	2.66
ATK 1	110.90	108	N/A	119.2	0.37	240	5.68	48.16	2.64
ATK 1	128.60	126	N/A	82.5	0.23	199	5.27	63.49	2.65
ATK 1	163.30	159	N/A	79.0	0.25	229	4.75	49.83	2.65
ATK 1	174.20	171	N/A	81.3	0.24	230	5.39	65.32	2.65
ATK 5	224.40	217	N/A	98.0	0.39	229	4.87	31.63	2.66
ATK 1	238.10	232	N/A	79.3	0.25	223	4.99	54.99	2.65
ATK 1	283.60	269	N/A	81.8	0.25	201	5.34	63.21	2.66

Table 1 (Cont'd)

Specimen No.		Vertical depth (m)	Elevation (m)	Young's modulus (GPa)	Poisson's ratio	Uniaxial compressive strength (MPa)	Zero pressure velocity (km/sec)	Dynamic young's Modulus (GPa)	Density (gm/cc)
ATK 1	320.25	305	N/A	67.4	0.25	226	4.25	40.04	2.66
ATK 5	337.50	323	N/A	64.1	0.34	224	4.76	39.16	2.66
ATK 1	361.40	342	N/A	72.3	0.21	231	5.15	62.44	2.65
ATK 1	400.70	380	N/A	72.4	0.20	227	5.13	63.48	2.68
ATK 5	424.05	405	N/A	71.9	0.30	241	5.33	56.14	2.66
ATK 1	433.50	409	N/A	69.7	0.25	226	4.87	52.37	2.65
ATK 1	475.50	445	N/A	52.8	0.20	221	4.85	56.10	2.65
ATK 1	505.40	474	N/A	75.2	0.24	212	3.66	30.12	2.65
ATK 1	540.10	505	N/A	67.0	0.24	179	3.63	29.63	2.65
ATK 5	534.20	508	N/A	61.0	0.27	212	3.94	33.05	2.66
ATK 1	594.20	552	N/A	64.8	0.28	162	3.11	19.97	2.64
ATK 1	630.40	582	N/A	56.9	0.20	170	3.70	33.72	2.65
ATK 5	625.60	588	N/A	62.5	0.19	235	5.01	61.27	2.68
ATK 1	641.20	592	N/A	60.3	0.28	194	4.51	42.16	2.65
ATK 5	708.70	660	N/A	57.5	0.27	206	4.15	37.63	2.73
ATK 1	715.20	662	N/A	75.7	0.26	202	5.68	70.14	2.65
ATK 1	747.30	690	N/A	62.6	0.24	216	4.65	48.61	2.65
ATK 1	788.30	725	N/A	58.3	0.26	193	4.20	38.35	2.66
ATK 1	812.50	744	N/A	69.2	0.25	190	3.85	32.73	2.65
ATK 5	818.10	752	N/A	55.0	0.20	178	3.84	35.17	2.65
ATK 1	848.90	778	N/A	72.0	0.22	223	4.61	48.21	2.59
ATK 5	867.70	785	N/A	61.7	0.28	202	3.92	31.97	2.66
ATK 1	902.15	818	N/A	71.3	0.27	220	3.87	31.76	2.65
ATK 5	918.20	836	N/A	59.5	0.25	217	3.92	33.93	2.65
ATK 1	924.00	839	N/A	80.8	0.25	209	5.04	56.10	2.65
ATK 5	951.30	870	N/A	97.1	0.36	223	4.22	28.19	2.66
ATK 1	979.90	887	N/A	72.0	0.27	189	4.14	36.35	2.65
ATK 5	975.60	890	N/A	59.9	0.23	208	3.79	32.96	2.66
ATK 1	1021.40	919	N/A	73.5	0.30	191	3.45	23.43	2.65
ATK 1	1035.00	930	N/A	83.5	0.23	250	5.31	63.97	2.63
ATK 5	1050.10	944	N/A	63.3	0.25	217	3.72	29.52	2.56

Table 1 (Cont'd)

Specimen No.	Vertical depth (m)	Elevation (m)	Young's modulus (GPa)	Poisson's ratio	Uniaxial compressive strength (MPa)	Zero pressure velocity (km/sec)	Dynamic young's Modulus (GPa)	Density (gm/cc)
ATK 1 1063.60	955	N/A	64.8	0.21	180	3.28	25.33	2.65
ATK 1 1079.10	968	N/A	87.4	0.17	207	4.57	51.49	2.65
ATK 1 1097.70	982	N/A	86.0	0.26	180	5.12	56.56	2.64
ATK 5 1107.90	985	N/A	57.0	0.31	185	4.04	31.32	2.66
ATK 1 1120.50	1002	N/A	87.6	0.26	257	5.76	71.59	2.64
ATK 1 1140.20	1019	N/A	55.2	0.23	154	2.14	10.43	2.64
ATK 5 1228.40	1052	N/A	70.8	0.22	293	4.70	51.27	2.65

Table 2 - Mechanical property/vertical depth interval data for Lac du Bonnet specimens

Depth interval	Mean vertical depth (m)	Mean Young's modulus (GPa)	Mean Poisson's ratio	Mean uniaxial compressive strength (MPa)	Mean zero Pressure velocity (km/sec)	Mean dynamic Young's modulus (GPa)
0.00 - 53.50	19.74	67.78	0.26	192	5.04	55.64
	(20.37)	(7.4)	(0.03)	(33)	(0.47)	(10.53)
66.36 - 122.66	95.70	74.39	0.24	208	5.35	63.05
	(20.34)	(6.3)	(0.06)	(32.6)	(0.44)	(13.99)
124.05 - 140.00	133.02	71.48	0.26	208	5.15	56.23
	(5.12)	(3.60)	(0.04)	(17)	(0.46)	(11.00)
150.55 - 177.95	164.76	70.32	0.25	194	5.07	56.06
	(10.65)	(5.86)	(0.02)	(13)	(0.31)	(9.19)
178.41 - 236.70	200.86	71.59	0.26	202	4.94	51.00
	(20.88)	(6.06)	(0.03)	(21)	(0.21)	(7.22)
238.45 - 279.78	261.14	66.30	0.24	199	4.31	41.61
	(15.32)	(5.34)	(0.03)	(13)	0.53)	(11.17)
280.53 - 357.45	305.35	66.14	0.24	188	4.57	46.60
	(28.10)	(6.12)	(0.01)	(34)	(0.36)	(7.13)
367.70 - 391.61	380.45	61.21	0.30	188	4.03	32.18
	(9.26)	(4.92)	(0.05)	(23)	(0.47)	(11.20)
391.80 - 426.80	413.02	59.81	0.29	193	3.70	28.49
	(17.49)	(7.04)	(0.03)	(34)	(0.53)	(10.77)
430.32 - 478.95	454.47	62.34	0.26	183	3.77	30.94
	(20.07)	(8.02)	(0.05)	(23)	(0.32)	(7.91)

Bracketed values are equal to one standard deviation.

Table 2 (Cont'd)

Depth interval	Mean vertical depth (m)	Mean Young's modulus (GPa)	Mean Poisson's ratio	Mean uniaxial compressive strength (MPa)	Mean zero Pressure velocity (km/sec)	Mean dynamic Young's modulus (GPa)
501.14 - 582.69	545.89	66.86	0.28	176	3.64	27.19
	(29.15)	(8.34)	(0.03)	(8)	(0.28)	(5.07)
614.80 - 738.70	671.93	63.57	0.28	164	3.31	22.45
	(42.97)	(5.41)	(0.05)	(9)	(0.37)	(5.84)
752.73 - 829.70	792.76	59.58	0.28	159	2.93	18.05
	(31.39)	(3.57)	(0.09)	(9)	(0.50)	(9.26)
929.83 - 1004.26	986.96	51.94	0.32	172	2.68	12.45
	(20.45)	(2.83)	(0.07)	(14)	(0.18)	(3.17)

Bracketed values are equal to one standard deviation.

Table 3 - Mechanical property/elevation interval data for Lac du Bonnet specimens

Elevation interval	Mean elevation (m above sea level)	Mean Young's modulus (GPa)	Mean Poisson's ratio	Mean uniaxial compressive strength (MPa)	Mean zero Pressure velocity (km/sec)	Mean dynamic Young's modulus (GPa)
271.56 - 186.20	224.32	75.9	0.24	210	5.44	66.9
	(28.94)	(5.5)	(0.03)	(32)	(0.40)	(9.7)
183.13 - 151.94	163.07	71.9	0.27	206	5.18	55.3
	(10.85)	(3.5)	(0.06)	(20)	(0.30)	(11.8)
148.60 - 120.80	133.97	71.0	0.24	207	5.10	58.2
	(10.29)	(5.3)	(0.02)	(20)	(0.44)	(10.1)
114.43 - 94.56	105.18	68.4	0.27	196	4.91	49.3
	(7.91)	(3.1)	(0.02)	(21)	(0.17)	(5.6)
71.26 - 20.03	41.04	70.7	0.24	203	4.64	48.6
	(17.35)	(7.7)	(0.04)	(15)	(0.55)	(11.3)
18.78 - -22.80	3.09	67.1	0.25	194	4.46	43.9
	(14.59)	(4.0)	(0.02)	(19)	(0.37)	(8.1)
-34.51 - -99.20	-75.81	61.8	0.29	183	4.19	35.8
	(20.10)	(5.0)	(0.05)	(33)	(0.48)	(11.9)
-101.30 - -138.31	-114.94	61.5	0.28	189	3.78	30.2
	(15.07)	(7.1)	(0.04)	(34)	(0.59)	(12.5)
-138.53 - -179.76	-154.86	58.6	0.28	186	3.76	29.61
	(17.61)	(5.5)	(0.05)	(25)	(0.30)	(7.59)
-188.30 - -278.91	-232.32	66.2	0.26	184	3.61	28.3
	(36.76)	(9.4)	(0.04)	(16)	(0.27)	(5.8)
-290.31 - -419.00	-356.57	65.7	0.28	167	3.54	25.4
	(46.21)	(5.1)	(0.05)	(10)	(0.29)	(5.2)

Table 3 (Cont'd)

Elevation interval	Mean elevation (m above sea level)	Mean Young's modulus (GPa)	Mean Poisson's ratio	Mean uniaxial compressive strength (MPa)	Mean zero Pressure velocity (km/sec)	Mean dynamic Young's modulus (GPa)
-454.00 - -648.92	-521.37	58.4	0.28	159	2.91	17.7
	(60.22)	(4.1)	(0.07)	(8)	(0.43)	(7.4)
-710.07 - -723.29	-712.40	52.0	0.33	174	2.66	11.9
	(4.14)	(2.5)	(0.06)	(13)	(0.18)	(2.8)

Table 4 - Mechanical property/vertical depth interval depth for Atikokan specimens

Vertical depth interval	Mean vertical depth (m)	Mean Young's modulus (GPa)	Mean Poisson's ratio	Mean uniaxial compressive strength (MPa)	Mean zero pressure velocity (km/sec)	Mean dynamic Young's modulus (GPa)
12 - 103	65	94.5	0.30	219	5.27	53.56
	(30)	(17.1)	(0.06)	(21)	(0.34)	(10.74)
108 - 217	156	92.0	0.30	225	5.19	51.69
	(42)	(17.0)	(0.08)	(15)	(0.38)	(13.63)
232 - 342	294	73.0	0.26	221	4.90	51.96
	(44)	(7.6)	(0.05)	(12)	(0.42)	(11.74)
380 - 474	422	68.4	0.24	225	5.17	51.64
	(37)	(8.9)	(0.04)	(11)	(0.34)	(12.69)
505 - 588	547	62.4	0.24	192	3.88	35.52
	(39)	(3.8)	(0.04)	(31)	(0.70)	(15.40)
592 - 725	666	62.9	0.26	202	4.64	47.37
	(49)	(7.4)	(0.01)	(9)	(0.62)	(13.45)
744 - 818	775	63.2	0.24	203	4.01	35.97
	(29)	(7.2)	(0.03)	(19)	(0.33)	(6.98)
836 - 890	864	73.9	0.27	209	4.22	37.51
	(26)	(15.8)	(0.0)	(13)	(0.49)	(10.81)
919 - 968	943	74.5	0.23	209	4.06	38.74
	(19)	(10.8)	(0.05)	(27)	(0.85)	(18.02)
982 - 1052	1008	71.3	0.26	214	4.35	44.23
	(29)	(15.4)	(0.04)	(58)	(1.39)	(23.77)

Table 5 - Statistical analysis of mechanical properties of granitic sample populations

Sample population		Density (gm/cc)	Uniaxial compressive strength (MPa)	Young's modulus (GPa)	Poisson's ratio	Zero pressure velocity (km/sec)
URL, WN & ATK	Mean :	2.64	195	67.6	0.27	4.26
n = 162	Std. deviation:	0.02	29	12.0	0.05	0.94
	Range :	2.56 - 2.75	95 - 293	27.4 - 123.4	0.13 - 0.43	2.14 - 5.76
URL & WN	Mean :	2.64	187	64.7	0.27	4.17
n = 112	Std. deviation:	0.02	27	8.9	0.05	0.93
	Range :	2.59 - 2.75	95 - 248	27.4 - 86.0	0.13 - 0.43	2.45 - 5.68
ATK	Mean :	2.65	212	73.9	0.26	4.53
n = 50	Std. deviation:	0.02	26	15.2	0.05	0.78
	Range :	2.56 - 2.73	154 - 293	52.8 - 123.4	0.17 - 0.39	2.14 - 5.76

Table 6 - Summary of triaxial results of URL, WN and ATK specimens

Specimen identification	Length (mm)	Diameter (mm)	Density (gm/cc)	Confining pressure (MPa)	Temperature (°C)	Triaxial strength (MPa)	Elastic modulus (GPa)
URL 1 179.82	121.18	44.72	2.64	3.5	21	272	65.79
URL 1 189.62	122.66	44.86	2.64	3.5	21	276	70.00
URL 5 127.62	121.84	44.45	2.64	3.5	21	285	67.94
URL 5 136.90	121.39	44.68	N/A	3.5	21	299	71.30
URL 6 224.50	117.65	44.50	2.65	3.5	21	280	68.87
URL 6 256.67	116.05	44.79	2.62	3.5	21	302	68.08
URL 7 132.00	118.07	44.51	2.68	3.5	21	315	70.66
URL 7 188.00	119.82	44.84	2.65	3.5	21	264	68.33
WN 1 323.93	N/A	44.93	N/A	3.5	21	283	71.02
WN 1 324.75	N/A	44.69	N/A	3.5	21	241	68.33
WN 1 169.70	111.29	44.56	2.65	3.5	21	273	53.10
ATK 1 660.54	125.78	44.37	2.68	3.5	21	262	53.19
ATK 1 660.80	128.80	44.40	2.65	3.5	21	266	44.90
						$(\overline{\sigma_1-\sigma_3})$ = 278	$\overline{E}$ = 64.73
						σ = 19.3	σ = 8.53
URL 6 374.22	125.50	44.28	2.63	5.0	21	303	56.59
URL 6 392.04	126.50	44.51	2.63	5.0	21	288	63.28
						$(\overline{\sigma_1-\sigma_3})$ = 295.5	$\overline{E}$ = 59.93
						$\pm$ 7.5	$\pm$ 3.34
URL 1 179.70	114.74	44.76	2.64	10.0	21	344	67.03
URL 1 189.23	115.22	44.50	2.64	10.0	21	363	67.61

Table 6 (Cont'd)

Specimen identification	Length (mm)	Diameter (mm)	Density (gm/cc)	Confining pressure (MPa)	Temperature (°C)	Triaxial strength (MPa)	Elastic modulus (GPa)
URL 2 1080.14	125.49	44.79	2.63	10.0	21	345	60.16
URL 2 1081.77	125.55	44.66	2.63	10.0	21	356	60.55
URL 5 128.46	115.00	44.30	2.65	10.0	21	371	70.99
URL 5 137.15	121.52	44.68	2.63	10.0	21	365	67.06
URL 6 224.62	115.10	44.80	2.65	10.0	21	384	68.26
URL 6 257.60	117.28	44.55	2.62	10.0	21	364	70.86
URL 6 373.69	118.03	44.55	2.63	10.0	21	344	66.32
URL 6 391.25	124.16	44.62	2.63	10.0	21	361	65.42
URL 7 144.00	118.02	44.41	2.63	10.0	21	383	69.75
URL 7 174.42	115.95	44.47	2.63	10.0	21	376	68.33
						$(\overline{\sigma_1-\sigma_3})$ = 363.0	$\bar{E}$ = 66.86
						σ = 14.1	σ = 3.48
URL 5 442.13	126.59	44.64	2.66	15.0	21	419	58.67
URL 5 442.94	118.31	44.42	2.66	15.0	21	367	59.34
						$(\overline{\sigma_1-\sigma_3})$ = 393	$\bar{E}$ = 58.00
						$\pm$ 26	$\pm$ 0.34
URL 1 179.45	119.80	44.76	2.64	17.0	21	429	69.42
URL 1 189.49	121.84	44.68	2.64	17.0	21	405	64.93
URL 5 127.74	122.54	44.68	2.62	17.0	21	436	71.11
URL 5 136.69	122.94	44.65	2.64	17.0	21	435	72.00

Table 6 (Cont'd)

Specimen identification	Length (mm)	Diameter (mm)	Density (gm/cc)	Confining pressure (MPa)	Temperature (°C)	Triaxial strength (MPa)	Elastic modulus (GPa)
URL 6 224.74	114.72	44.80	2.65	17.0	21	435	66.63
URL 6 257.72	115.42	44.52	2.63	17.0	21	434	68.69
WN 1 323.82	N/A	44.91	N/A	17.0	21	459	74.88
WN 1 324.16	N/A	44.93	N/A	17.0	21	445	66.40
WN 1 169.24	111.29	44.56	2.65	17.0	21	492	56.89
ATK 1 660.93	129.10	44.58	2.65	17.0	21	422	64.74
ATK 1 661.06	128.32	44.37	2.65	17.0	21	427	60.00
						$(\overline{\sigma_1-\sigma_3})$ = 438	$\bar{E}$ = 66.88
						σ = 22	σ = 5.23
URL 6 391.48	124.38	44.58	2.63	25.0	21	488	68.87
URL 6 391.71	122.61	44.49	2.63	25.0	21	488	63.36
						$(\overline{\sigma_1-\sigma_3})$ = 488	$\bar{E}$ = 66.11
						± 0	± 275
URL 1 179.58	121.86	44.88	2.62	26.0	21	516	67.33
URL 1 179.95	121.18	44.78	2.64	26.0	21	479	69.33
URL 5 128.33	115.24	44.53	2.65	26.0	21	506	66.41
URL 5 137.28	122.96	44.68	2.63	26.0	21	505	64.88
URL 6 225.50	118.05	44.77	2.64	26.0	21	507	64.86
URL 6 257.84	113.07	44.51	2.64	26.0	21	513	66.21

Table (6 Cont'd)

Specimen identification	Length (mm)	Diameter (mm)	Density (gm/cc)	Confining pressure (MPa)	Temperature (°C)	Triaxial strength (MPa)	Elastic modulus (GPa)
URL 7 150.26	119.34	44.45	2.59	26.0	21	506	66.31
URL 7 166.55	119.75	44.55	2.63	26.0	21	543	69.16
						$(\overline{\sigma_1-\sigma_3})$ = 509	$\bar{E}$ = 66.81
						σ = 17.5	σ = 1.71
URL 5 441.85	125.59	44.53	2.66	30.0	21	534	60.99
URL 5 442.54	125.63	44.64	2.66	30.0	21	539	61.25
						$(\overline{\sigma_1-\sigma_3})$ = 536.5	$\bar{E}$ = 61.12
						$\pm$ 2.5	$\pm$ 0.13
URL 1 180.20	123.14	44.74	2.63	35.0	21	534	71.03
URL 1 189.90	120.12	44.72	2.63	35.0	21	563	69.26
URL 2 1080.41	125.72	44.61	2.63	35.0	21	601	65.44
URL 2 1081.49	123.40	44.67	2.63	35.0	21	532	67.04
URL 5 128.20	113.28	44.45	2.63	35.0	21	562	69.41
URL 5 137.02	121.72	44.68	2.64	35.0	21	534	65.54
URL 6 224.90	118.81	44.81	2.65	35.0	21	552	69.46
URL 6 258.08	118.63	44.52	2.63	35.0	21	551	70.10
URL 7 134.16	117.94	44.94	2.63	35.0	21	611	69.02
URL 7 181.00	119.20	44.46	2.64	35.0	21	558	69.18
URL B4 9.75	117.95	44.08	2.64	35.0	21	606	70.01

Table 6 (Cont'd)

Specimen identification	Length (mm)	Diameter (mm)	Density (gm/cc)	Confining pressure (MPa)	Temperature (°C)	Triaxial strength (MPa)	Elastic modulus (GPa)
URL B26 5.00	115.87	44.68	2.63	35.0	21	576	76.20
WN 1 323.70	N/A	44.93	N/A	35.0	21	552	68.74
WN 1 324.06	N/A	44.96	N/A	35.0	21	558	64.26
WN 1 169.8	111.30	44.45	N/A	35.0	21	609	60.55
WN 1 169.48	111.11	44.45	N/A	35.0	21	545	60.28
ATK 1 661.19	129.24	44.63	2.64	35.0	21	541	65.48
ATK 1 661.45	129.08	44.53	2.65	35.0	21	538	62.13
						$(\overline{\sigma_1-\sigma_3})$ = 562	$\bar{E}$ = 67.20
						σ = 27	σ = 3.59
URL 2 1080.93	126.64	44.49	2.62	50	21	674	67.46
URL 2 1082.31	125.60	44.63	2.64	50	21	636	64.57
URL 2 1080.63*	120.75	44.52	2.63	50	21	651	66.74
URL 2 1082.03*	124.60	44.69	2.63	50	21	638	64.11
URL 6 374.85	124.76	44.47	2.65	50	21	597	69.21
URL 6 392.27	125.79	44.73	2.63	50	21	629	68.52
						$(\overline{\sigma_1-\sigma_3})$ = 637.5	$\bar{E}$ = 66.77
						σ = 25.4	σ = 2.07
URL 5 441.57	122.05	44.63	2.66	55	21	317**	62.94
URL 5 442.36	125.61	44.64	2.66	55	21	708	63.80

* Samples were previously cycled at σ_3 = 70.0 MPa.

** Failure occurred along a pre-existing fracture plane.

Table 6 (Cont'd)

Specimen identification	Length (mm)	Diameter (mm)	Density (gm/cc)	Confining pressure (MPa)	Temperature (°C)	Triaxial strength (MPa)	Elastic modulus (GPa)
URL 2 1080.63	120.75	44.52	2.63	70	21	727†	66.71
URL 2 1082.03	124.60	44.69	2.63	70	21	713†	66.27
URL 6 226.25	116.45	44.74	2.65	3.5	100	275	74.67
URL 6 256.51	117.15	44.56	2.62	3.5	100	278	71.42
WN 1 342.01	113.00	44.47	2.63	3.5	100	280	65.03
WN 1 345.95	104.52	44.49	2.62	3.5	100	279	62.34
WN 1 157.12	111.40	44.60	N/A	3.5	100	264	47.49
WN 1 157.00	111.00	44.60	N/A	3.5	100	275	45.00
ATK 1 660.67	127.48	44.37	2.64	3.5	100	265	57.14
ATK 1 662.52	128.55	44.37	2.64	3.5	100	260	58.00
						$(\overline{\sigma_1-\sigma_3})$ = 272	$\overline{E}$ = 60.14
						σ = 7.8	σ = 10.49
URL 6 225.74	116.11	44.74	2.68	10.0	100	286*	73.40
URL 6 258.20	115.91	44.57	2.62	10.0	100	335	70.76
				10.0	100		$\overline{E}$ = 72.08
							± 1.32
URL 6 225.62	115.33	44.76	2.66	17.0	100	421	72.73
URL 6 258.46	114.49	44.53	2.63	17.0	100	413	76.73

† Triaxial strengths were estimated using failure strength determined at σ_3 = 50 MPa.

Table 6 (Cont'd)

Specimen identification	Length (mm)	Diameter (mm)	Density (gm/cc)	Confining pressure (MPa)	Temperature (°C)	Triaxial strength (MPa)	Elastic modulus (GPa)
WN 1 342.69	111.48	44.50	2.63	17.0	100	430	71.70
WN 1 345.77	118.95	44.50	2.62	17.0	100	446	71.70
WN 1 156.89	111.40	44.60	N/A	17.0	100	425	60.62
WN 1 156.74	111.40	44.60	N/A	17.0	100	412	55.87
ATK 1 661.71	129.16	44.50	2.67	17.0	100	425	56.80
ATK 1 663.78	128.84	44.48	2.63	17.0	100	400	60.00
						$(\overline{\sigma_1-\sigma_3})$ = 421.5	$\overline{E}$ = 65.77
						σ = 13.7	σ = 8.26
URL 6 225.90	116.3	44.75	2.66	26.0	100	459	61.91
URL 6 258.82	117.21	44.53	2.62	26.0	100	496	65.66
						$(\overline{\sigma_1-\sigma_3})$ = 277.5	$\overline{E}$ = 63.78
						± 18.5	± 1.8
URL 6 226.02	115.65	44.77	2.64	35.0	100	534	74.44
URL 6 258.70	115.80	44.52	2.63	35.0	100	536	73.54
WN 1 342.40	115.42	44.40	2.64	35.0	100	561	73.00
WN 1 344.50	116.33	44.40	2.64	35.0	100	537	58.07
WN 1 156.63	110.90	44.50	N/A	35.0	100	550	46.65
WN 1 156.51	111.00	44.50	N/A	35.0	100	557	54.50
ATK 1 661.58	128.34	44.50	2.65	35.0	100	525	79.47
ATK 1 664.17	129.16	44.58	2.65	35.0	100	507	71.43
						$(\overline{\sigma_1-\sigma_3})$ = 538	$\overline{E}$ = 66.39
						σ = 17.7	σ = 11.69

Table 6 (Cont'd)

Specimen identification	Length (mm)	Diameter (mm)	Density (gm/cc)	Confining pressure (MPa)	Temperature (°C)	Triaxial strength (MPa)	Elastic modulus (GPa)
URL 6 226.37	116.35	44.75	2.64	3.5	200	239	63.99
URL 6 227.42	116.57	44.76	2.64	3.5	200	217	61.22
WN 1 341.75	115.34	44.50	2.62	3.5	200	213	47.65
WN 1 347.29	106.22	44.50	2.63	3.5	200	263	42.14
WN 1 347.17	111.78	44.50	2.63	3.5	200	254	53.03
WN 1 156.40	111.40	44.50	N/A	3.5	200	225	41.37
WN 1 156.28	111.40	44.50	N/A	3.5	200	229	37.32
ATK 1 661.32	129.11	44.42	2.66	3.5	200	276	51.25
ATK 1 662.22	127.61	44.42	2.63	3.5	200	261	57.78
ATK 1 664.30	128.98	44.42	2.68	3.5	200	260	52.67
						$\overline{(\sigma_1-\sigma_3)}$ = 244	$\overline{E}$ = 50.84
						σ = 21.9	σ = 8.79
URL 6 226.60	116.85	44.72	2.63	10.0	200	299	82.87[a]
URL 6 228.33	117.76	44.82	2.63	10.0	200	330	72.68
						$\overline{(\sigma_1-\sigma_3)}$ = 214.5	
						± 15.5	
URL 6 226.72	117.64	44.78	2.64	17.0	200	359	68.74
URL 6 259.26	116.42	44.56	2.63	17.0	200	359	62.84

[a]Valve was tested as an outlier.

Table 6 (Cont'd)

Specimen identification	Length (mm)	Diameter (mm)	Density (gm/cc)	Confining pressure (MPa)	Temperature (°C)	Triaxial strength (MPa)	Elastic modulus (GPa)
WN 1 346.21	115.70	44.50	2.63	17.0	200	395	69.65
WN 1 343.00	111.20	44.50	2.62	17.0	200	406	71.50
WN 1 159.48	111.30	44.70	N/A	17.0	200	361	44.74
WN 1 171.78	111.30	44.70	N/A	17.0	200	403	44.27
ATK 1 662.35	129.31	44.45	2.64	17.0	200	411	47.80
ATK 1 664.43	129.44	44.50	2.66	17.0	200	396	47.69
						$(\overline{\sigma_1-\sigma_3})$ = 386	$\bar{E}$ = 57.15
						σ = 22.6	σ = 12.10
URL 6 227.30	115.06	44.78	2.64	26.0	200	448	70.11
URL 6 228.18	115.64	44.76	2.65	26.0	200	460	81.93*
						$(\overline{\sigma_1-\sigma_3})$ = 454 ± 6	
URL 6 225.10	117.60	44.78	2.63	35.0	200	550	75.85
URL 6 226.94	116.03	44.76	2.65	35.0	200	501	67.31
WN 1 343.92	111.30	44.50	2.63	35.0	200	531	69.21
WN 1 341.54	112.34	44.50	2.61	35.0	200	507	73.98
WN 1 344.04	109.92	44.60	2.62	35.0	200	514	61.98
WN 1 171.66	111.40	44.70	N/A	35.0	200	504	45.65
WN 1 171.46	111.50	44.60	N/A	35.0	200	500	48.92

* Valve treated as an outlier.

Table 6 (Cont'd)

Specimen identification	Length (mm)	Diameter (mm)	Density (gm/cc)	Confining pressure (MPa)	Temperature (°C)	Triaxial strength (MPa)	Elastic modulus (GPa)
ATK 1 662.48	128.14	44.27	2.66	35.0	200	499	60.25
ATK 1 664.56	127.44	44.66	2.63	35.0	200	492	51.00
						$\overline{(\sigma_1-\sigma_3)}$ = 511	$\bar{E}$ = 61.57
						σ = 18.4	σ = 11.05

Table 7 - Mohr Coulomb analysis URL, WN and ATK, 21°C

Confining pressure (MPa)	Cohesion (MPa)	Internal friction angle ϕ	Failure angle θ	Failure plane stresses τ(MPa)	σ(MPa)
3.5	28	62°	76°	66	20
10.0	35	58°	74°	93	36
17.0	43	56°	73°	123	55
26.0	60	50°	70°	162	84
35.0	75	46°	68°	192	111

Table 8 - Mohr Coulomb analysis URL, WN and ATK, 100°C

Confining pressure (MPa)	Cohesion (MPa)	Internal friction angle ϕ	Failure angle θ	Failure plane stresses τ(MPa)	σ(MPa)
3.5	28	62°	76°	65	20
17.0	47	54°	72°	125	58
35.0	71	46°	68°	186	109

Table 9 - Mohr Coulomb analysis URL, WN and ATK, 200°C

Confining pressure (MPa)	Cohesion (MPa)	Internal friction angle ϕ	Failure angle θ	Failure plane stresses τ(MPa)	σ(MPa)
3.5	29	58°	74°	65	22
17.0	40	54°	72°	114	54
35.0	64	46°	68°	175	104

Table 10 - Mohr Coulomb analysis URL and WN, 21°C

Confining pressure (MPa)	Cohesion (MPa)	Internal friction angle ϕ	Failure angle θ	Failure plane stresses τ(MPa)	σ(MPa)
3.5	33	58°	74°	72	23
10.0	34	58°	74°	94	37
17.0	43	56°	73°	124	55
26.0	62	50°	70°	163	85
35.0	72	48°	69°	191	109

Table 11 - Mohr Coulomb analysis URL and WN, 100°C

Confining pressure (MPa)	Cohesion (MPa)	Internal friction angle ϕ	Failure angle θ	Failure plane stresses τ(MPa)	σ(MPa)
3.5	32	58°	74°	71	23
17.0	43	54°	72°	122	55
35.0	75	46°	68°	190	111

Table 12 - Mohr Coulomb analysis URL and WN, 200°C

Confining pressure (MPa)	Cohesion (MPa)	Internal friction angle ϕ	Failure angle θ	Failure plane stresses τ(MPa)	σ(MPa)
3.5	27	58°	74°	62	21
17.0	37	54°	72°	109	51
35.0	64	46°	68°	176	104

Table 13 - Mohr Coulomb analysis; ATK, 21°C

Confining pressure (MPa)	Cohesion (MPa)	Internal friction angle ϕ	Failure angle θ	Failure plane stresses τ(MPa)	σ(MPa)
3.5	27	60.0°	75.0°	66	21
17.0	37	57.0°	73.5°	116	51
35.0	82	44.0°	65.0°	194	117

Table 14 - Mohr Coulomb analysis; ATK, 100°C

Confining pressure (MPa)	Cohesion (MPa)	Internal friction angle ϕ	Failure angle θ	Failure plane stresses τ(MPa)	σ(MPa)
3.5	25	63.0°	76.5°	60	18
17.0	50	51.0°	70.5°	129	63
35.0	70	45.0°	67.5°	182	110

Table 15 - Mohr Coulomb analysis; ATK, 200°C

Confining pressure (MPa)	Cohesion (MPa)	Internal friction angle ϕ	Failure angle θ	Failure plane stresses τ(MPa)	σ(MPa)
3.5	28	61.0°	75.5°	64	20
17.0	44	54.0°	72.0°	119	56
35.0	92	38.0°	64.0°	195	130

Table 16 - Triaxial strength (MPa) vs confining pressure and temperature

Confining pressure	Temperature (°C)		
(MPa)	21	100	200
3.5	278 (19)	272 (8)	244 (22)
10.0	363 (14)		
17.0	438 (22)	422 (14)	386 (23)
26.0	509 (18)		
35.0	562 (27)	538 (18)	511 (18)

Values in brackets represent one standard deviation.

Table 17 - Tangent modulus of elasticity (GPa) vs confining pressure and temperature

Confining pressure	Temperature (°C)		
(MPa)	21	100	200
3.5	64.73 (8.53)	72.08 (10.49)	50.84 (8.79)
10.0	66.86 (3.48)		
17.0	66.88 (5.23)	65.77 (8.26)	57.15 (12.10)
26.0	66.81 (1.71)		
35.0	67.20 (3.59)	66.39 (11.69)	61.57 (11.05)

Values in brackets represent one standard deviation.

Table 18 - Brazilian tensile strengths of Lac du Bonnet specimens

Borehole WN 4		Borehole URL 1		Borehole URL 2		Borehole URL 5		Borehole URL 6		Borehole URL 7	
Specimen No.	Tensile strength (MPa)	Specimen No.	Tensile strength (MPa)	Specimen No.	Tensile strength (MPa)	Specimen No.	Tensile strength (MPa)	Specimen No.	Tensile strength (MPa)	Specimen No.	Tensile strength (MPa)
409.00	10.64	177.50	9.27	1080.27	6.97	127.87	8.81	374.46	8.71	61.36	11.44
469.25	12.99	184.34	9.58	1080.29	6.94	133.12	9.81	374.48	8.66	61.39	10.73
482.35	10.47	184.37	9.58	1080.78	7.12	133.25	8.16	374.80	8.46	138.46	10.69
505.57	12.44	191.67	9.53	1080.80	6.63	138.98	9.93	374.82	8.39	139.77	12.07
551.45	11.21	283.07	8.96	1081.64	7.46	274.61	7.99	391.60	5.96	139.80	10.79
564.40	11.52	292.87	8.62	1082.17	7.96	274.64	9.02	391.84	7.82	143.27	10.30
603.60	12.06	293.00	8.08	1082.19	6.22	277.78	7.16	391.87	7.80	159.20	10.11
631.70	11.87	300.00	8.18			281.73	6.17			159.23	11.36
660.30	11.06					441.70	9.31			159.26	9.86
692.70	11.37					441.73	9.87			163.74	10.13
719.10	11.65					442.08	9.97			163.77	9.49
747.20	8.64					442.10	8.75			163.80	8.93
789.90	11.36					442.49	10.51			170.71	10.12
809.70	8.66					442.51	9.95			181.81	8.20
841.10	11.45					442.77	10.10			184.71	7.41
836.60	10.66					442.80	9.46			197.87	10.41
906.80	11.52										
928.30	10.53										

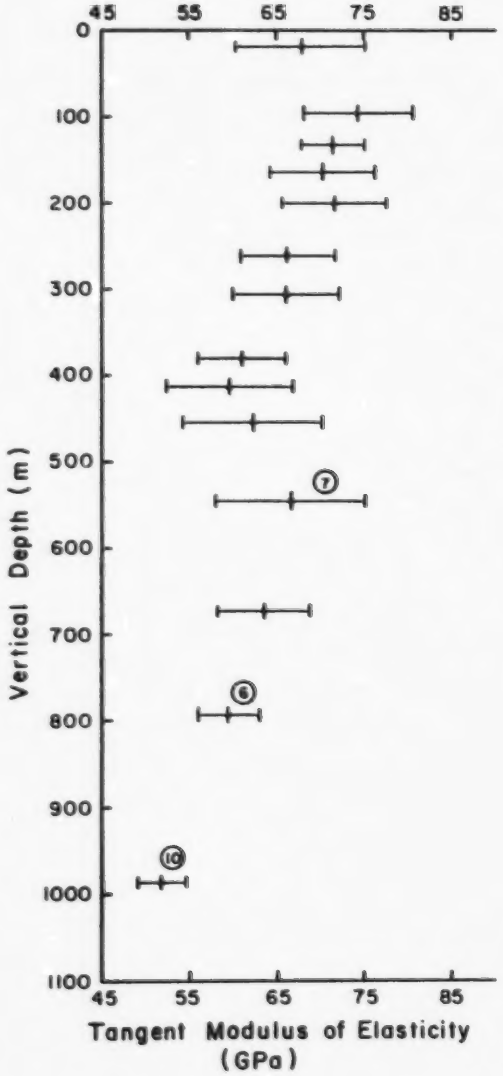

Fig. 1 - Tangent modulus of elasticity vs vertical depth; URL and WN

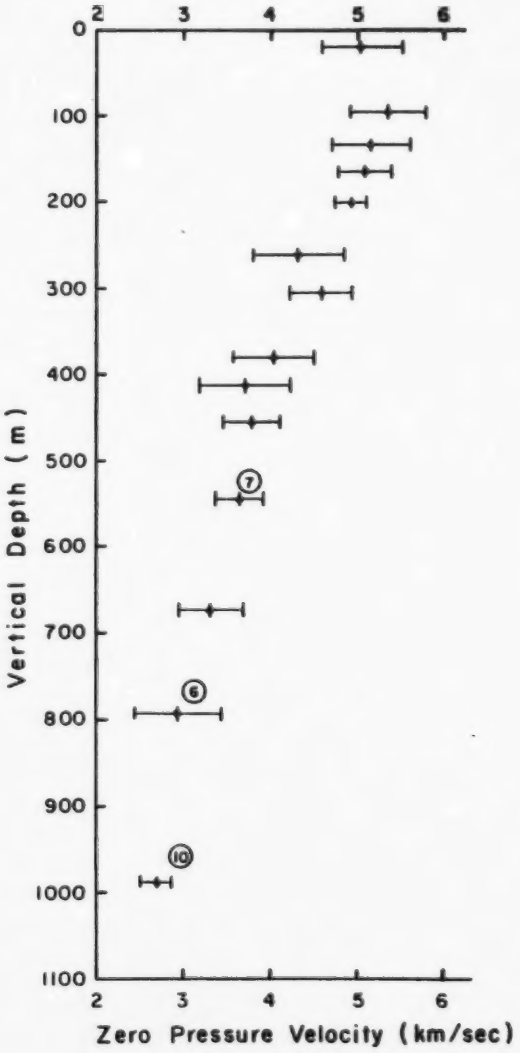

Fig. 2 - Zero pressure velocity vs vertical depth; URL and WN

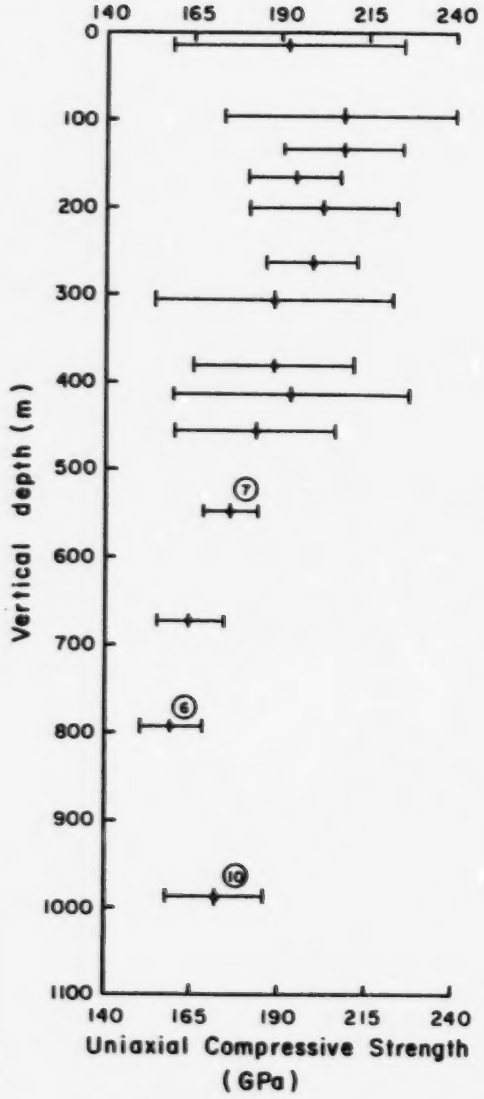

Fig. 3 - Uniaxial compressive strength vs vertical depth; URL and WN

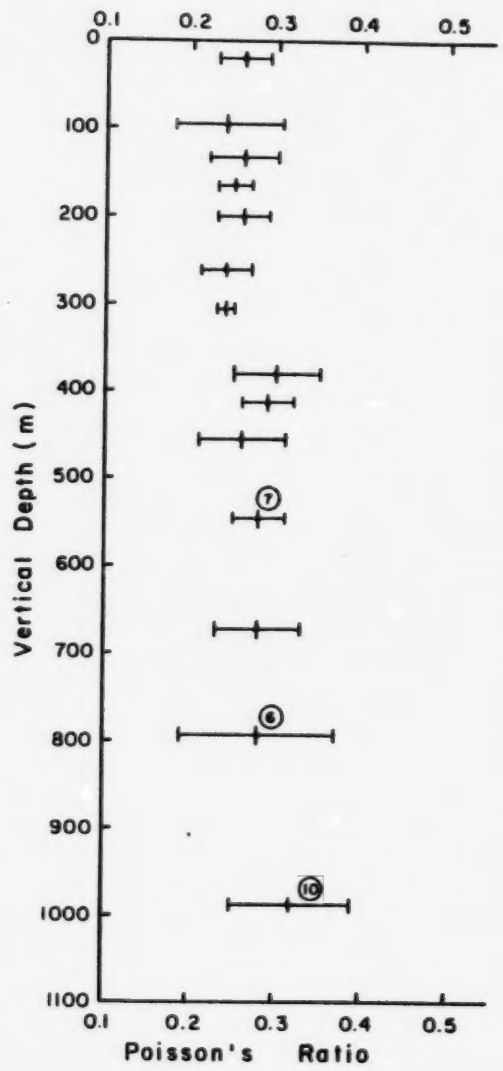

Fig. 4 - Poisson's ratio vs vertical depth; URL and WN

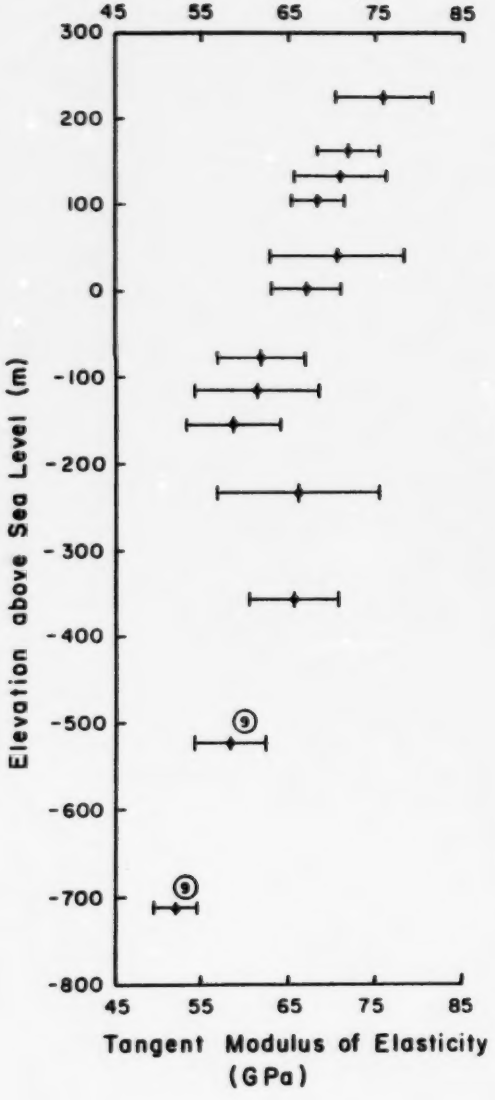

Fig. 5 - Tangent modulus of elasticity vs elevation above sea level, URL and WN

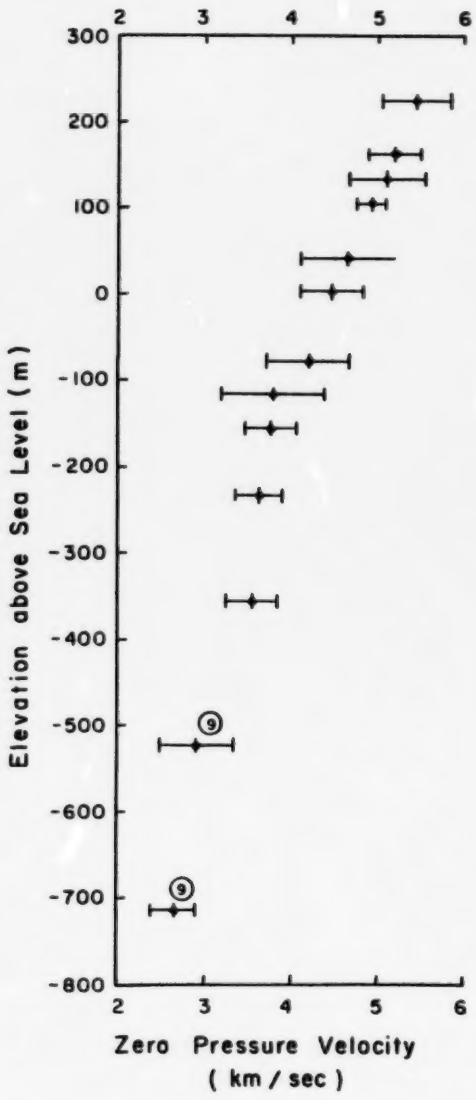

Fig. 6 - Zero pressure velocity vs elevation above sea level, URL and WN

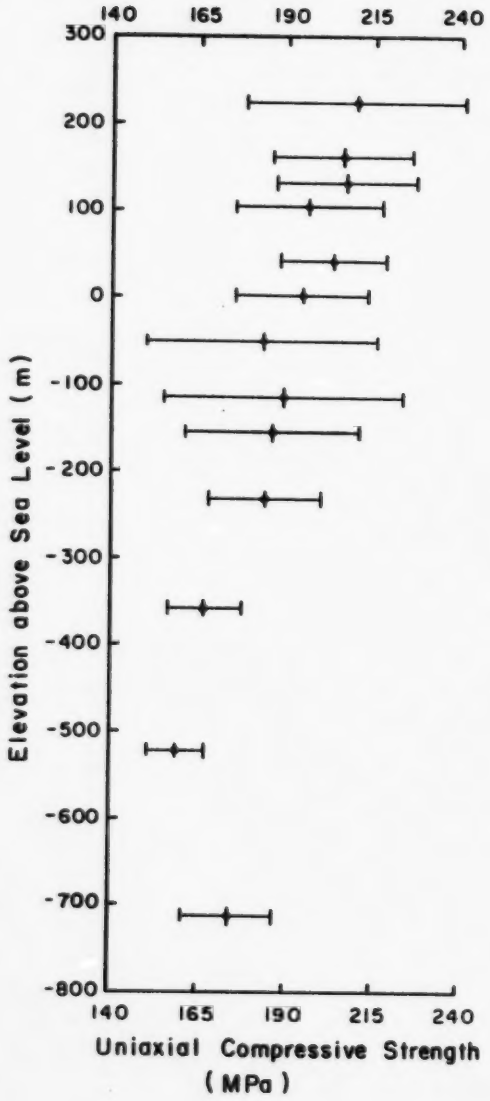

Fig. 7 - Uniaxial compressive strength vs elevation above sea level, URL and WN

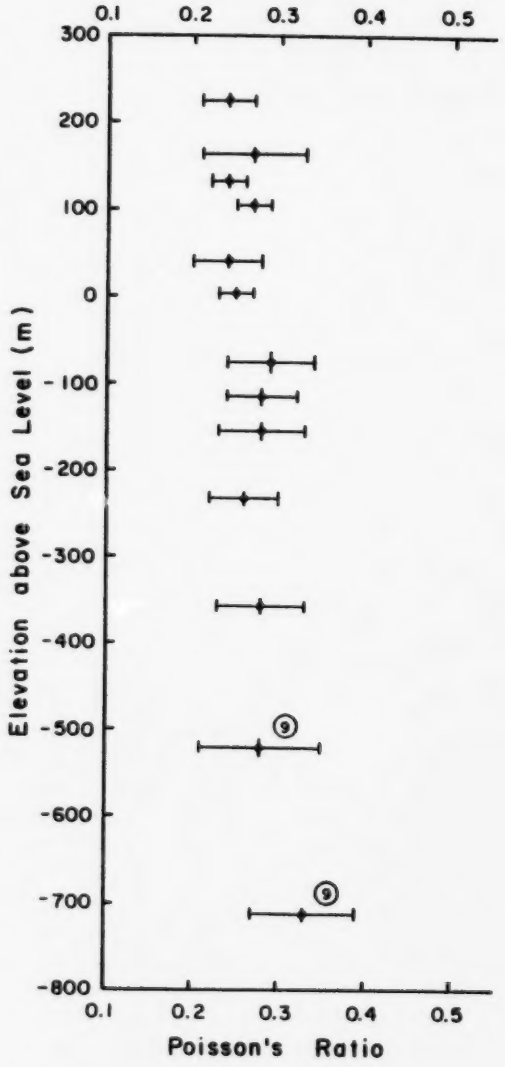

Fig. 8 - Poisson's ratio vs elevation above sea level, URL and WN

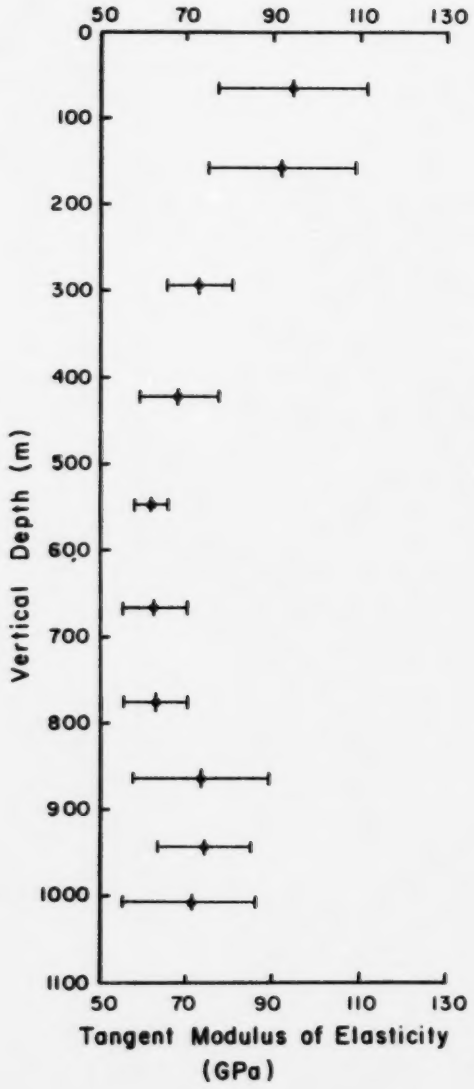

Fig. 9 - Tangent modulus of elasticity vs vertical depth, ATK

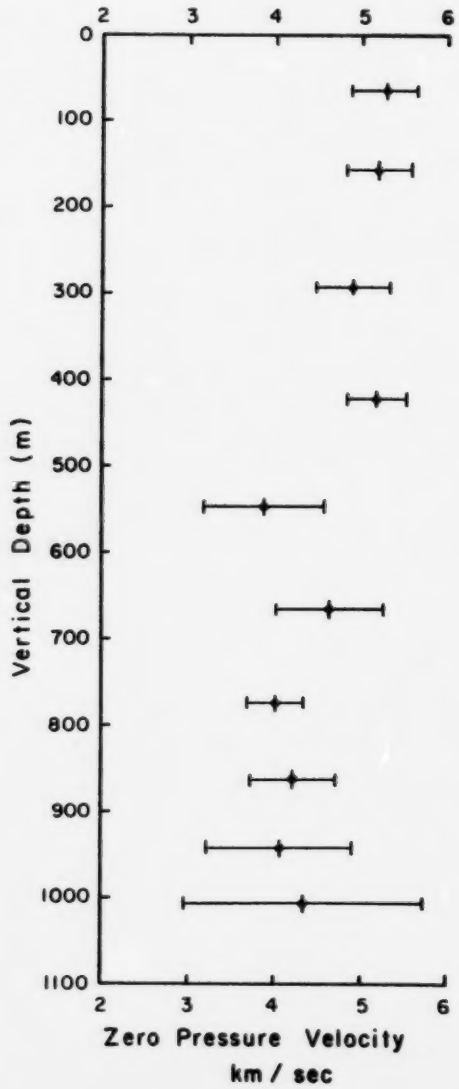

Fig. 10 - Zero pressure velocity vs vertical depth, ATK

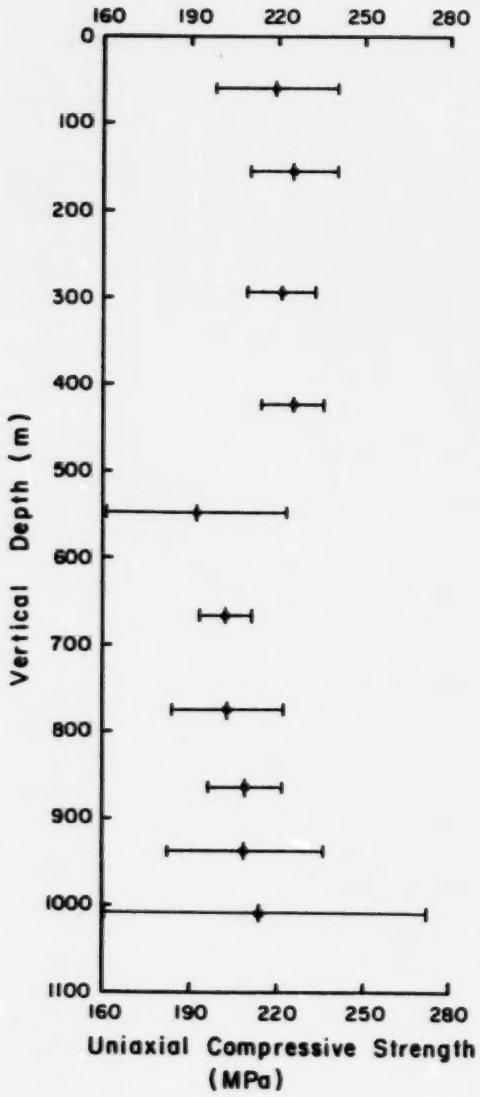

Fig. 11 - Uniaxial compressive strength vs vertical depth, ATK

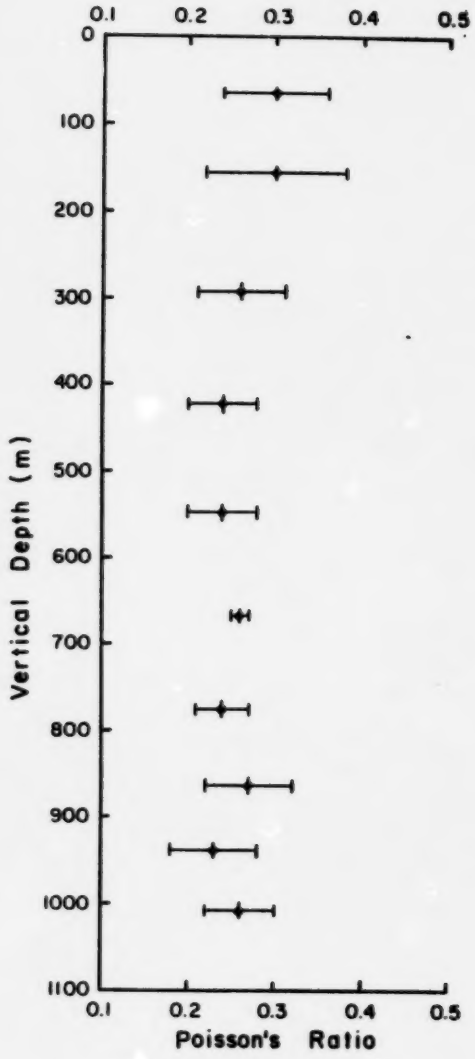

Fig. 12 - Poisson's ratio vs vertical depth, ATK

FIG.13: MOHR'S CIRCLE AND STRENGTH ENVELOPE: URL, WN & ATK, 21 C

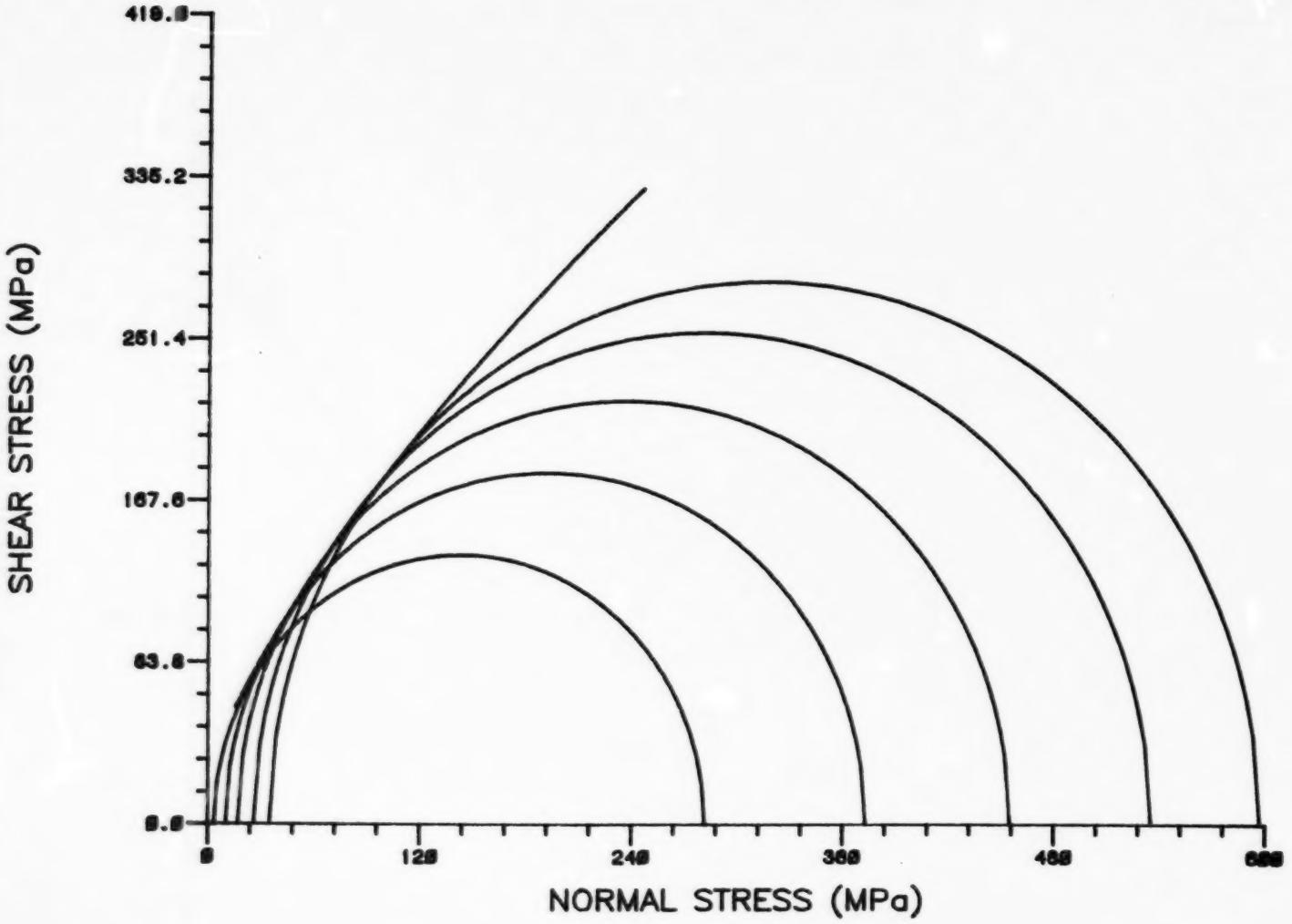

Fig. 13 - Mohr's circle and strength envelope: URL, WN and ATK, 21°C

FIG.14: MOHR'S CIRCLE AND STRENGTH ENVELOPE: URL, WN & ATK, 100 C

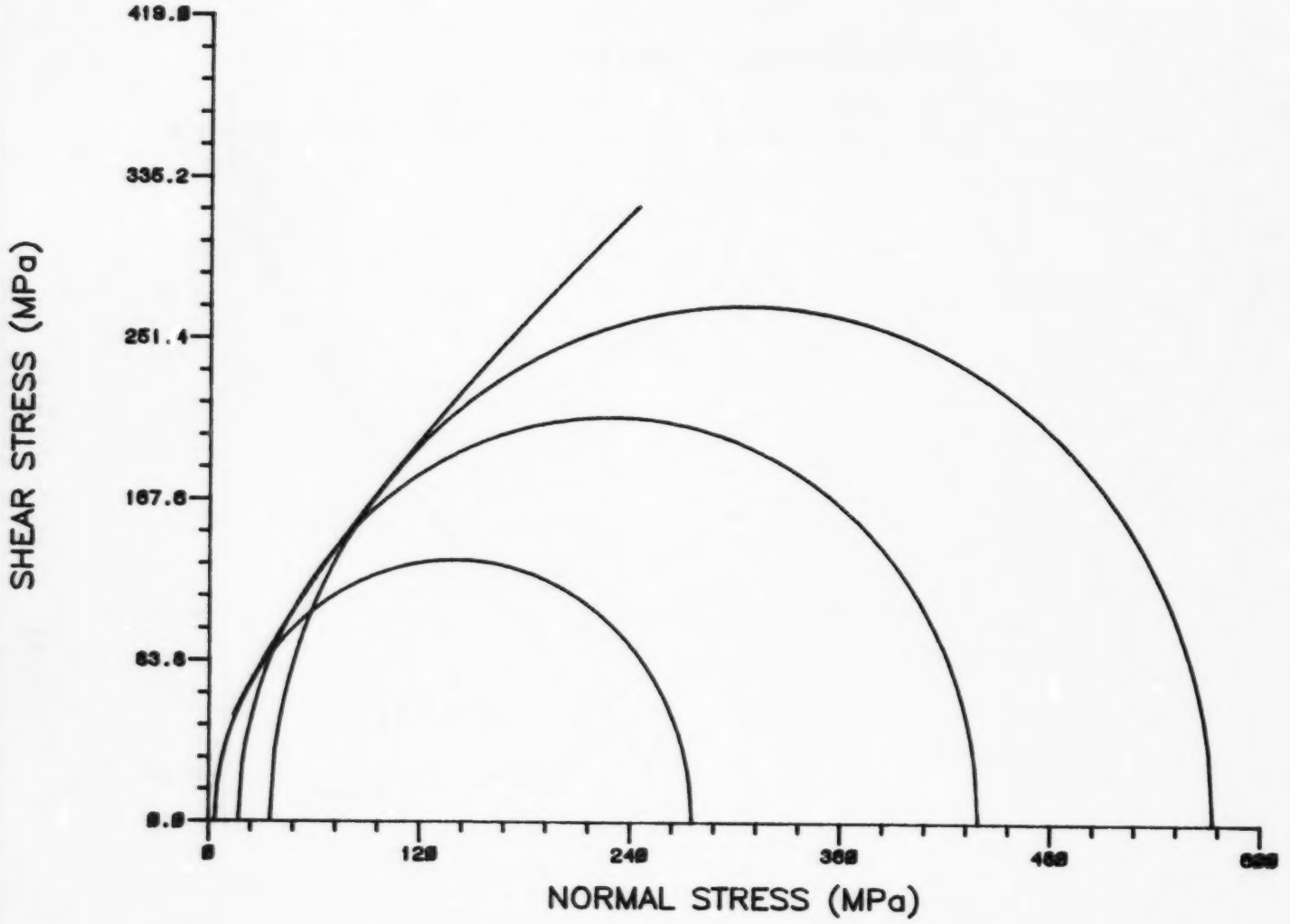

Fig. 14 - Mohr's circle and strength envelope: URL, WN and ATK, 100°C

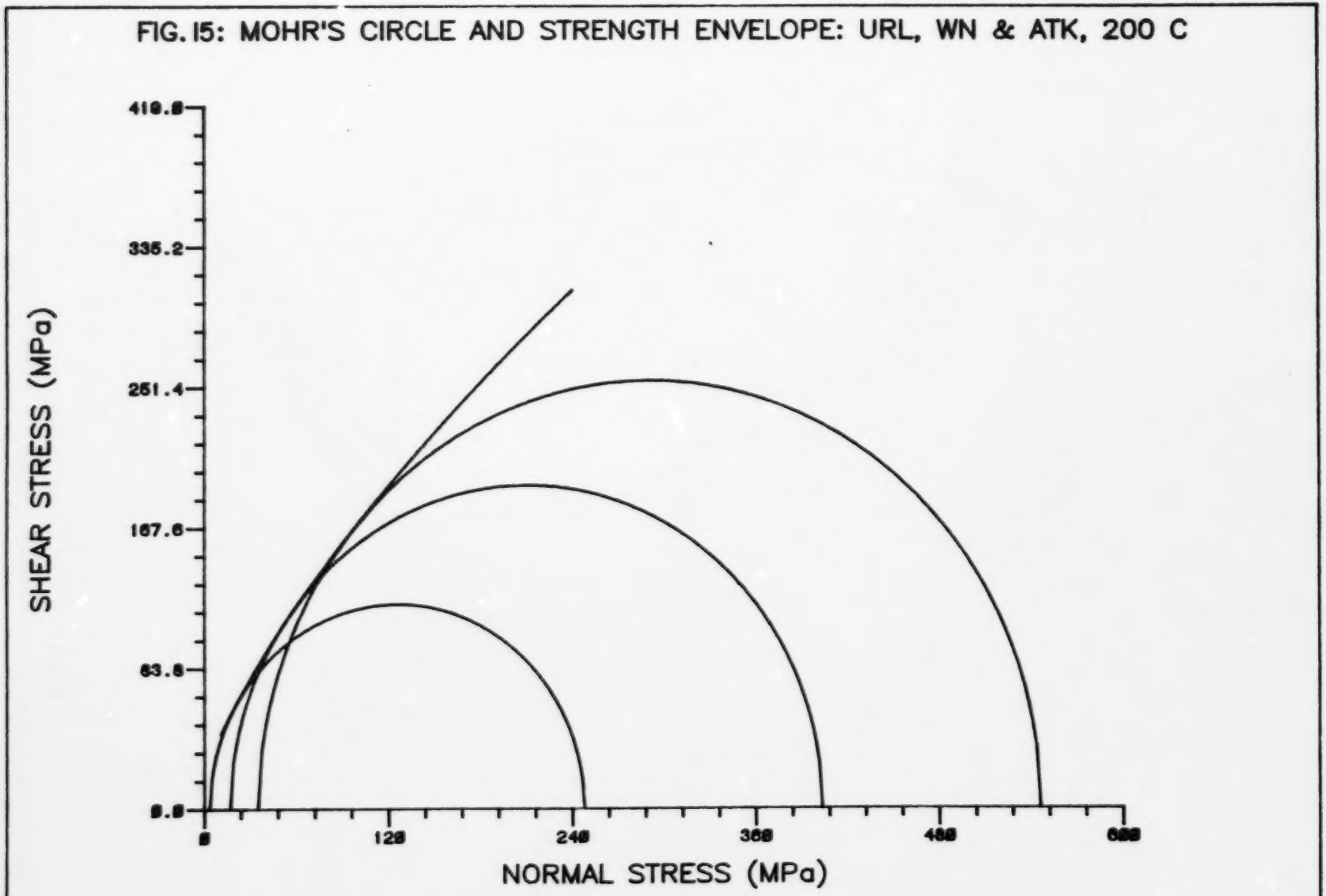

Fig. 15 - Mohr's circle and strength envelope: URL, WN and ATK, 200°C

FIG. 16: MOHR'S CIRCLE AND STRENGTH ENVELOPE: URL & WN, 21 C

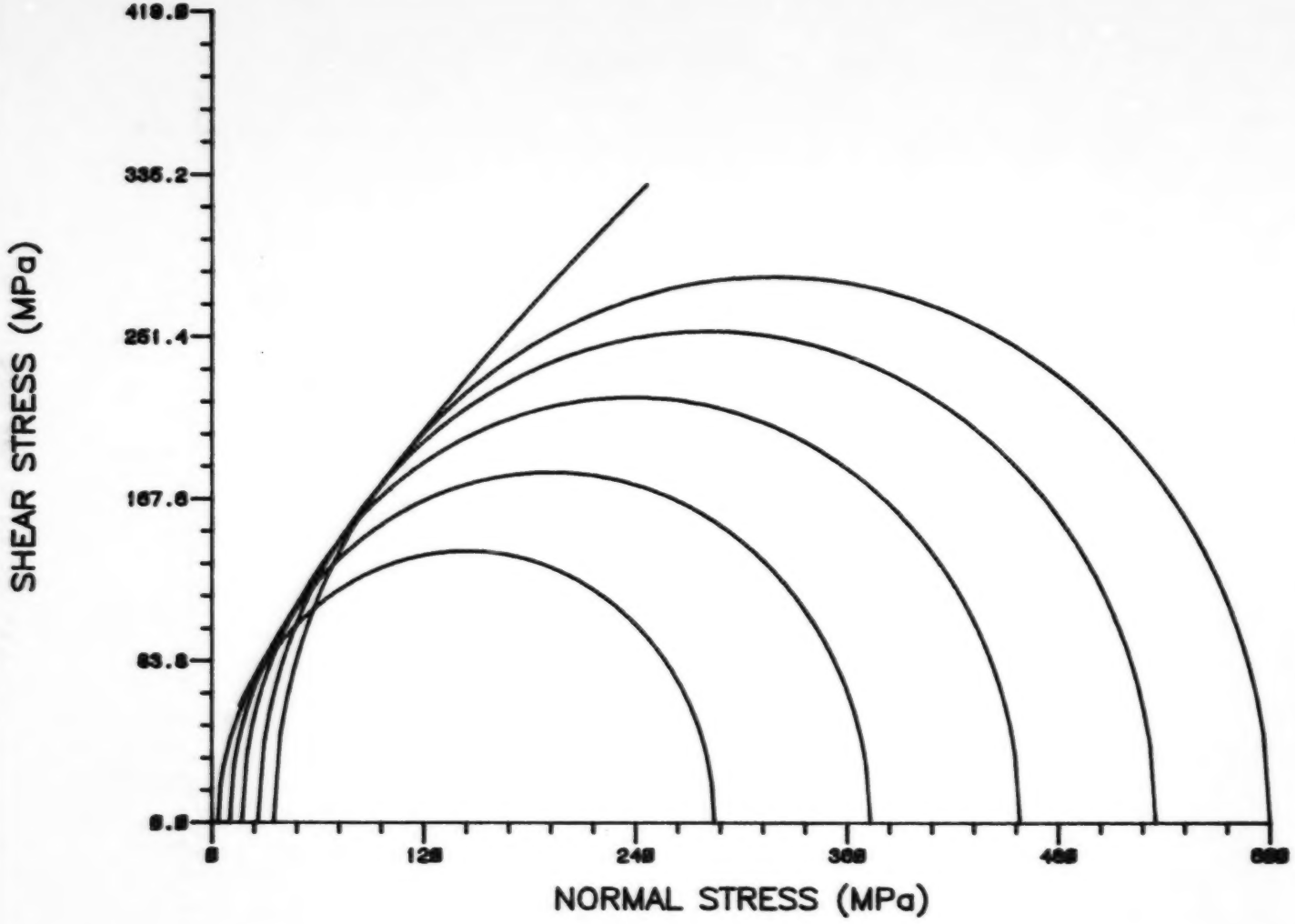

Fig. 16 - Mohr's circle and strength envelope: URL and WN, 21°C

FIG.17: MOHR'S CIRCLE AND STRENGTH ENVELOPE: URL & WN, 100 C

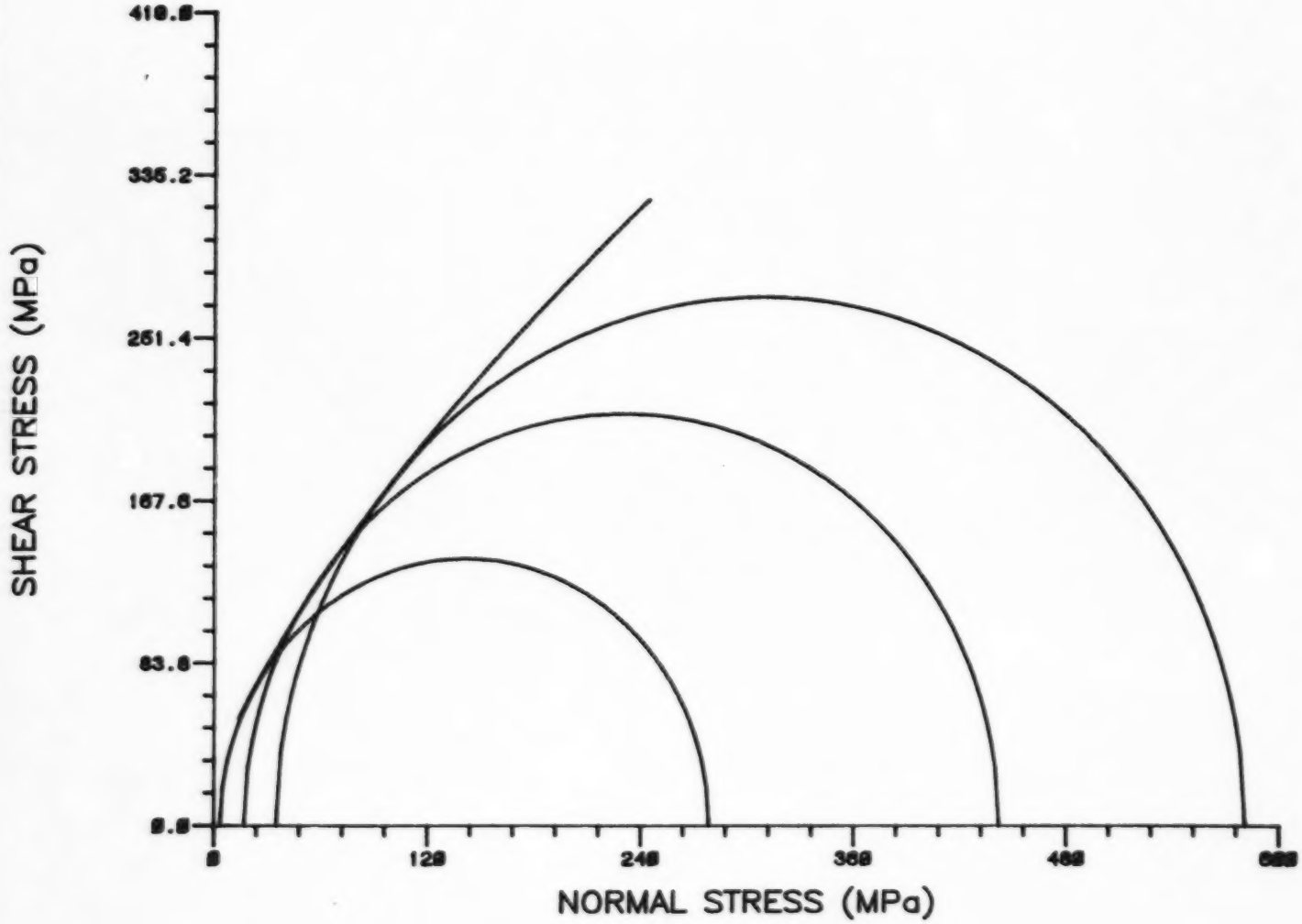

Fig. 17 - Mohr's circle and strength envelope: URL and WN, 100°C

FIG. 18: MOHR'S CIRCLE AND STRENGTH ENVELOPE: URL & WN, 200 C

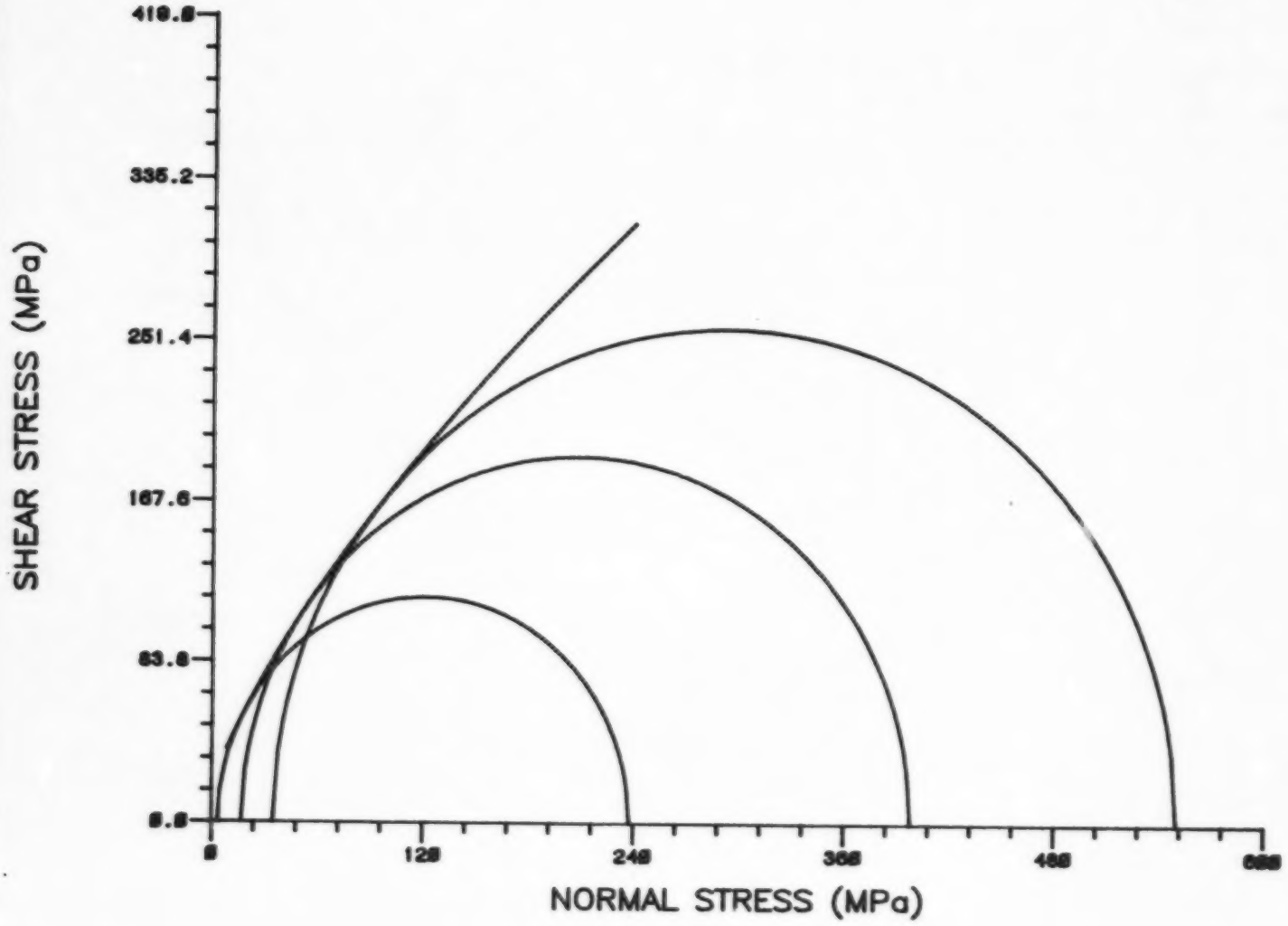

Fig. 18 - Mohr's circle and strength envelope: URL and WN, 200°C

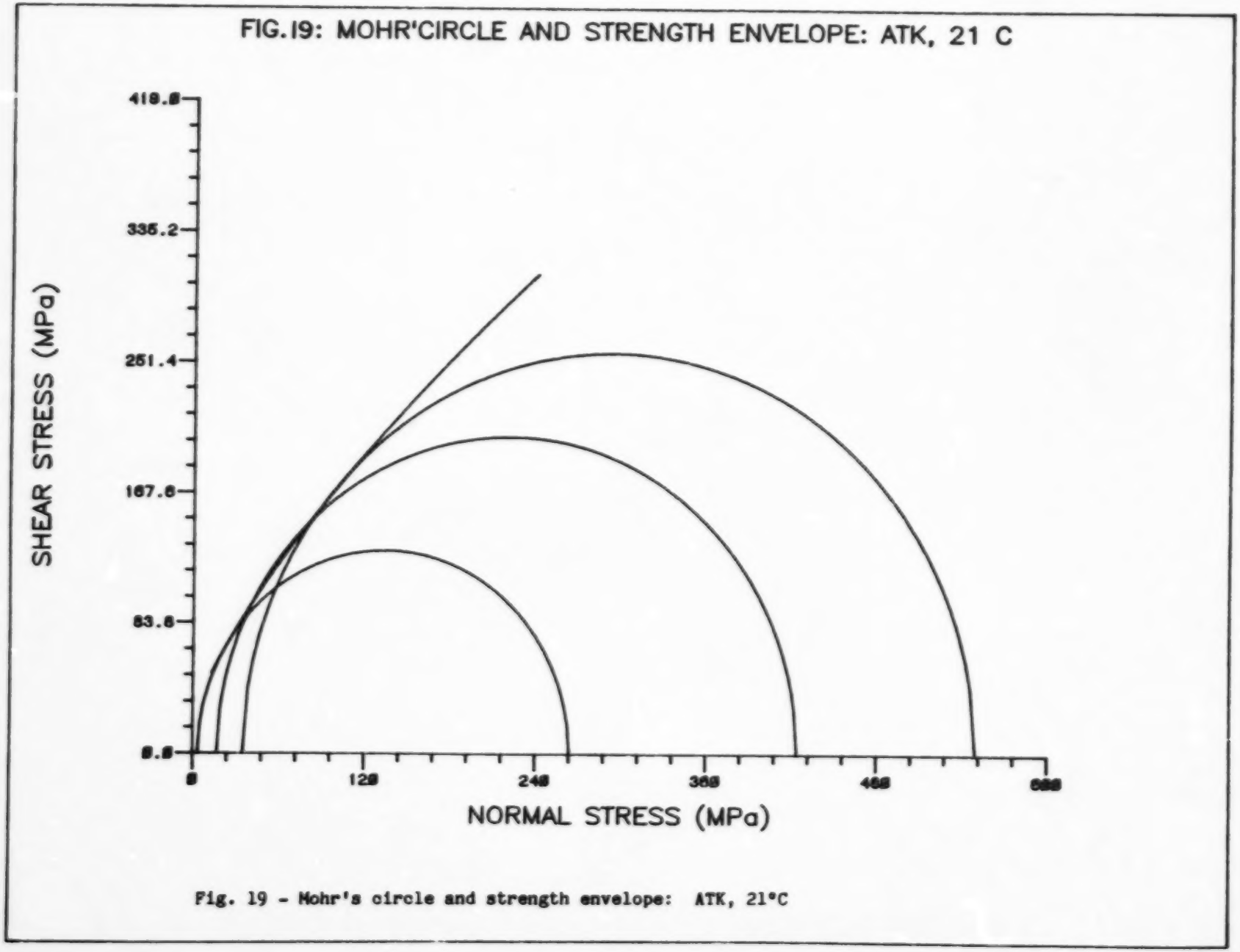

Fig. 19 - Mohr's circle and strength envelope: ATK, 21°C

FIG.20: MOHR'S CIRCLE AND STRENGTH ENVELOPE: ATK, 100 C

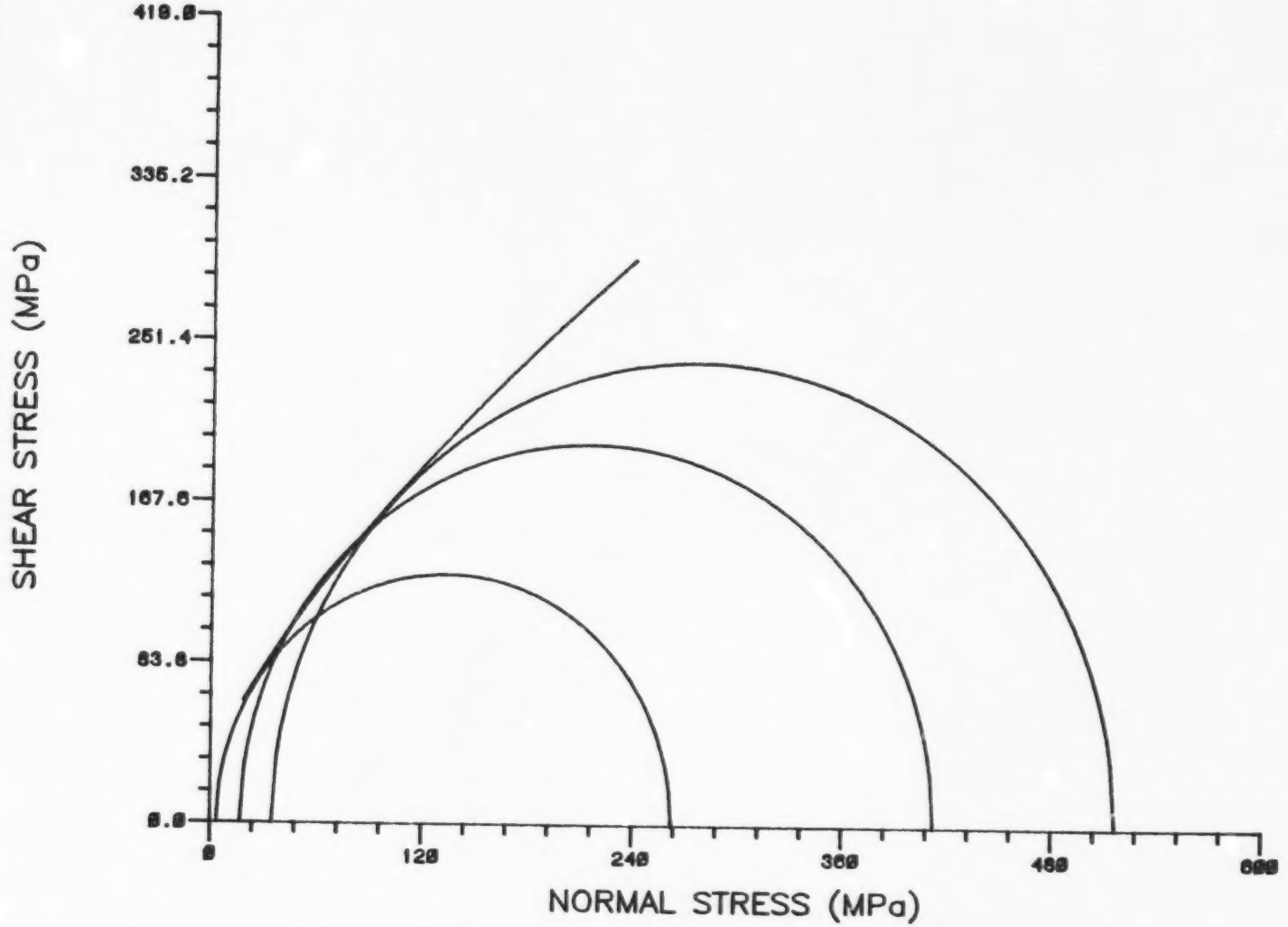

Fig. 20 - Mohr's circle and strength envelope: ATK, 100°C

FIG. 21: MOHR'S CIRCLE AND STRENGTH ENVELOPE: ATK, 200 C

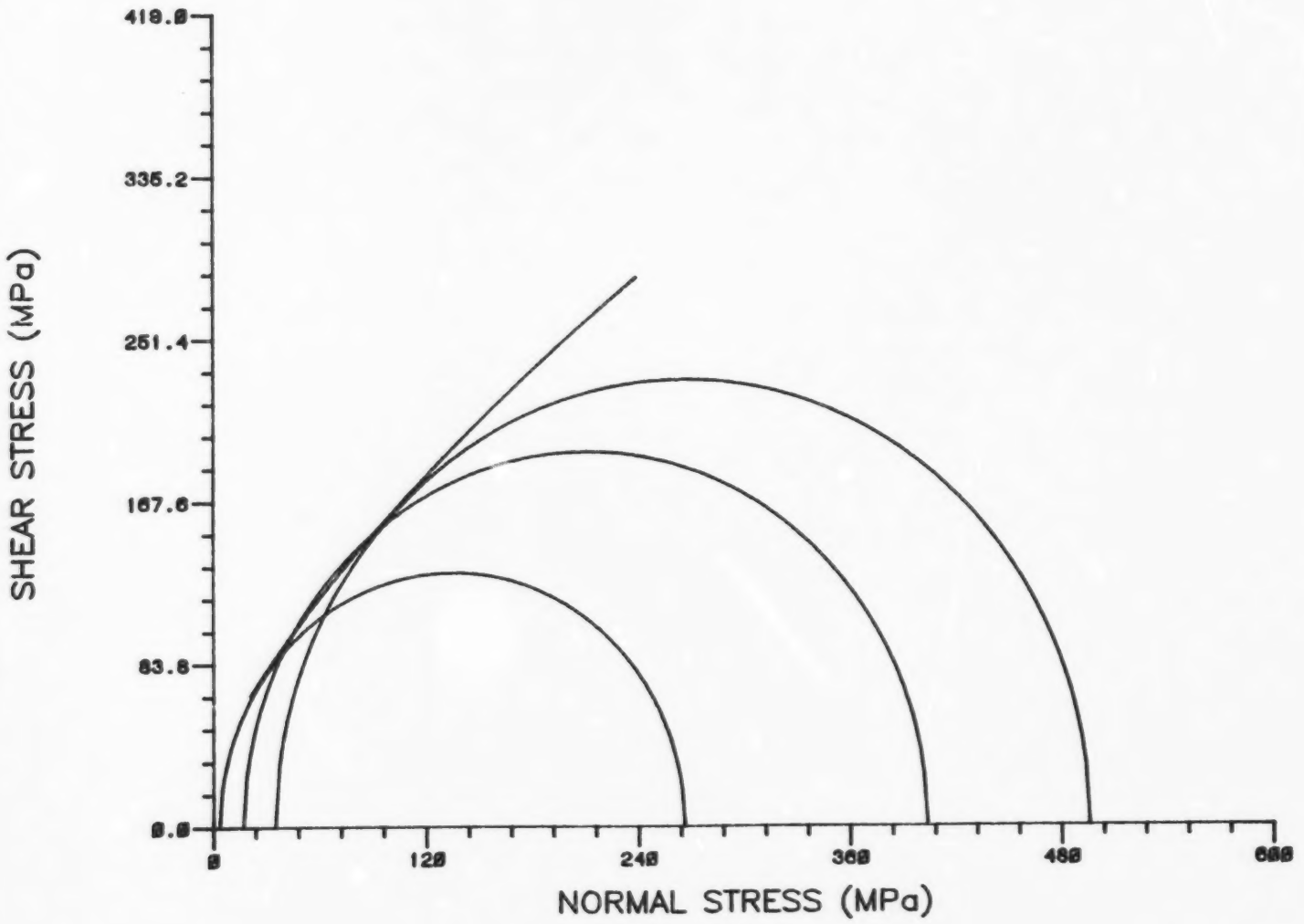

Fig. 21 - Mohr's circle and strength envelope: ATK, 200°C

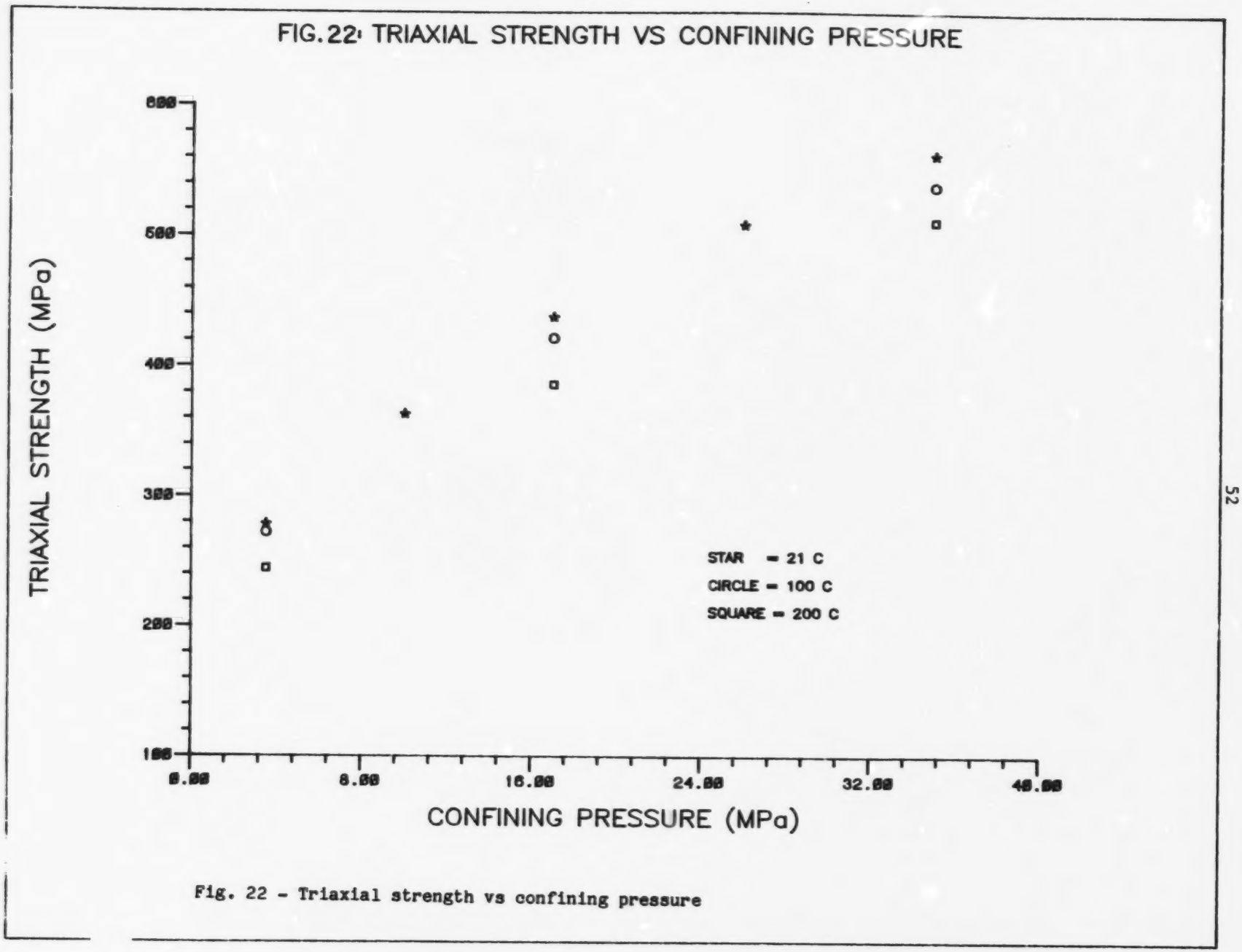

Fig. 22 - Triaxial strength vs confining pressure

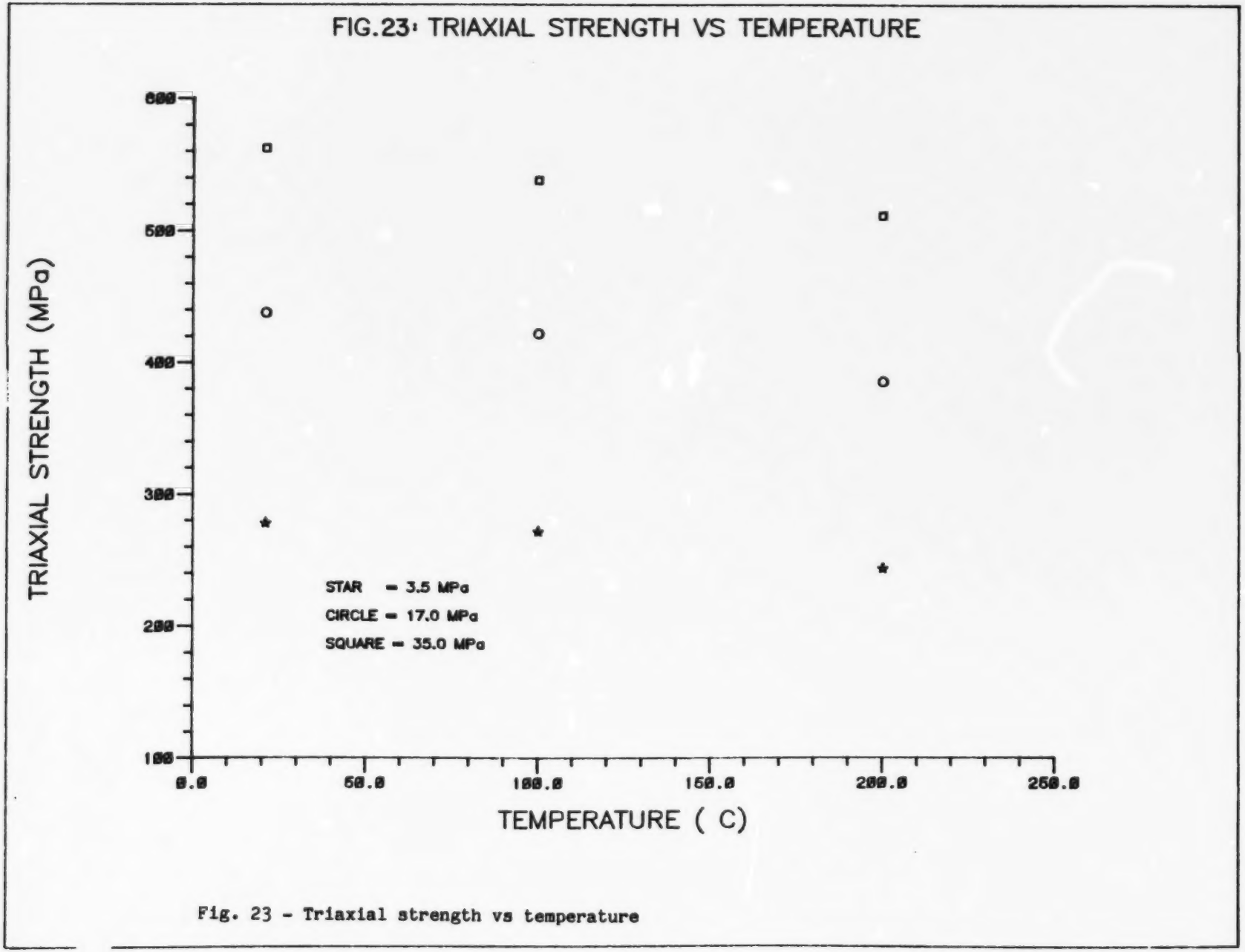

Fig. 23 - Triaxial strength vs temperature

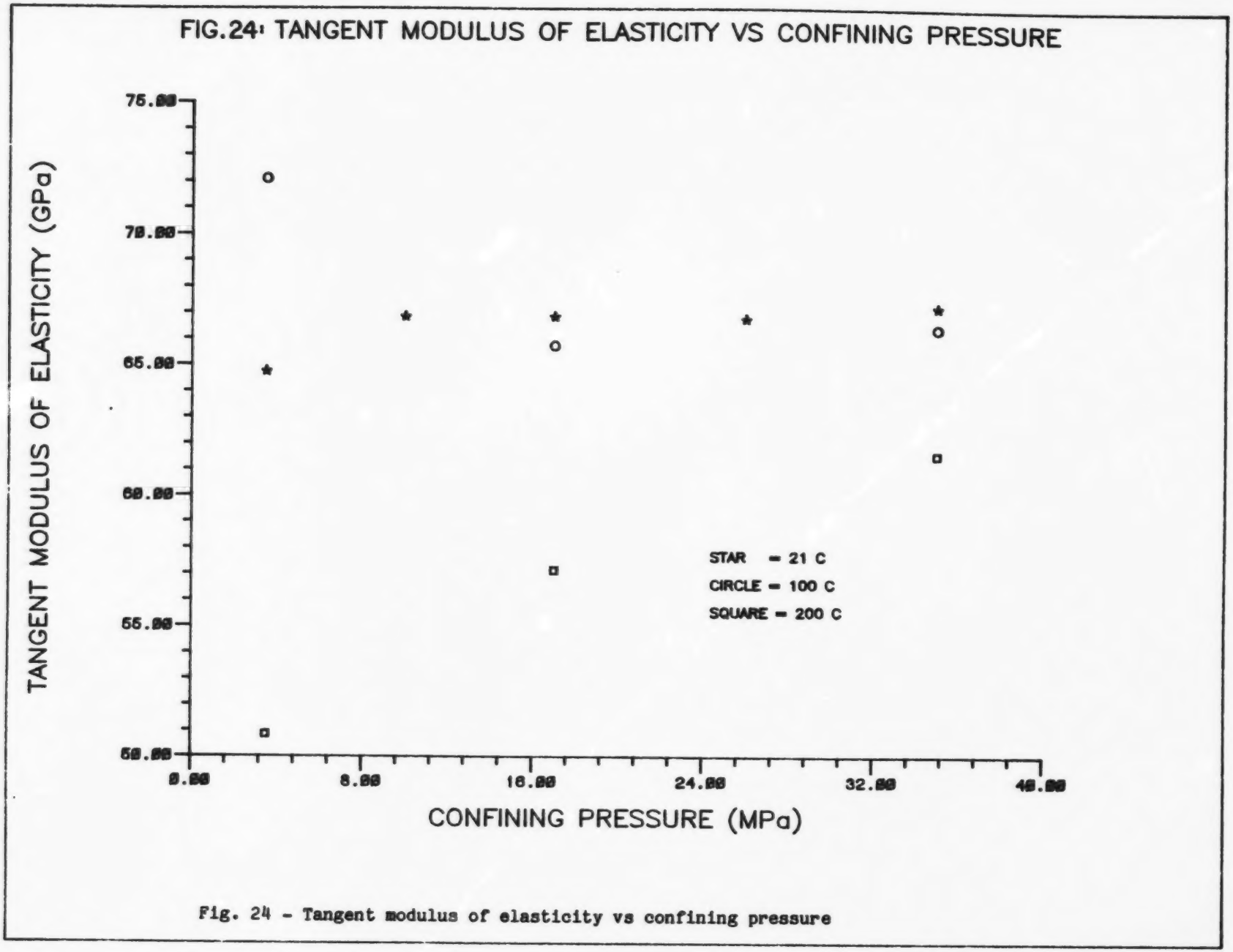

Fig. 24 - Tangent modulus of elasticity vs confining pressure

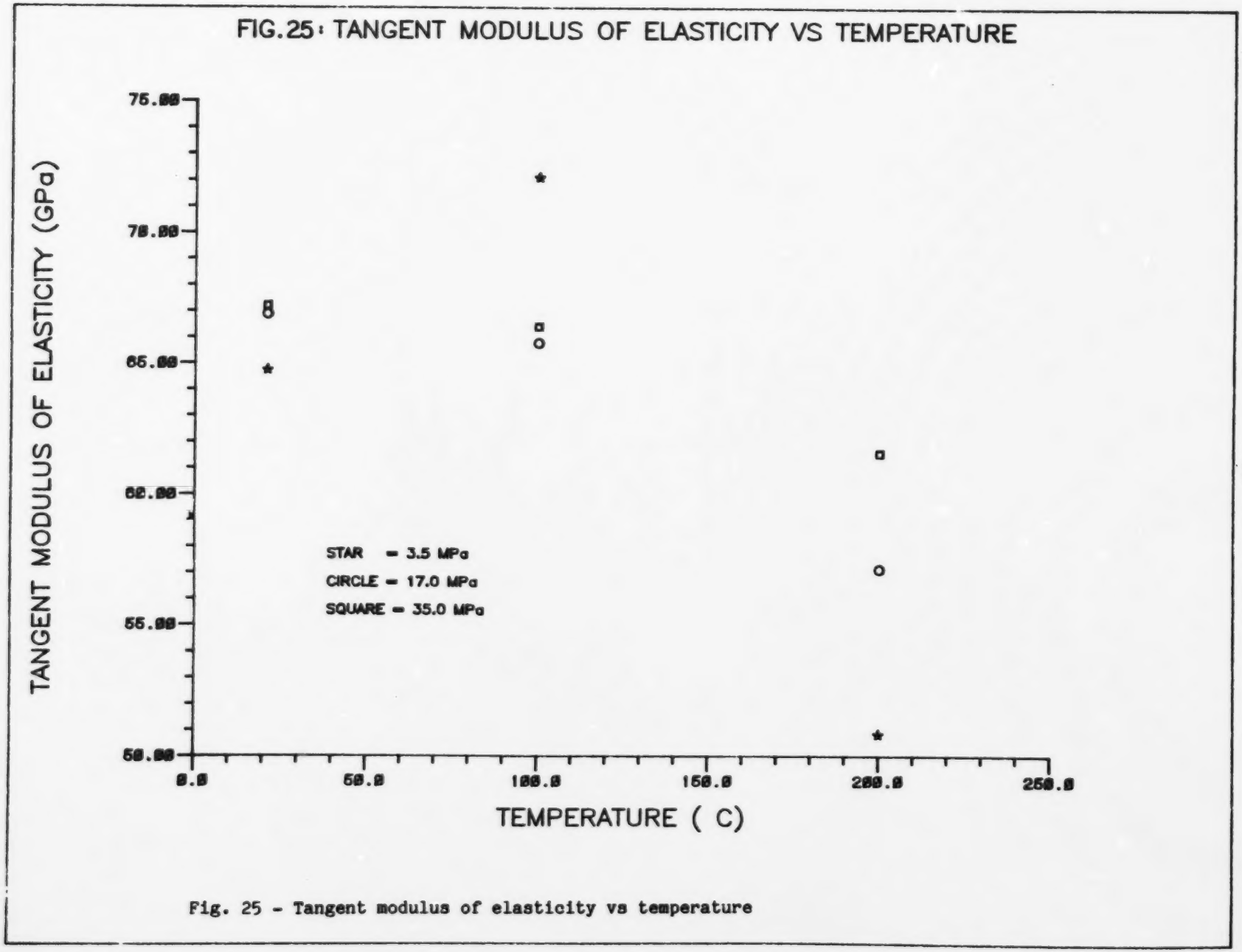

Fig. 25 - Tangent modulus of elasticity vs temperature

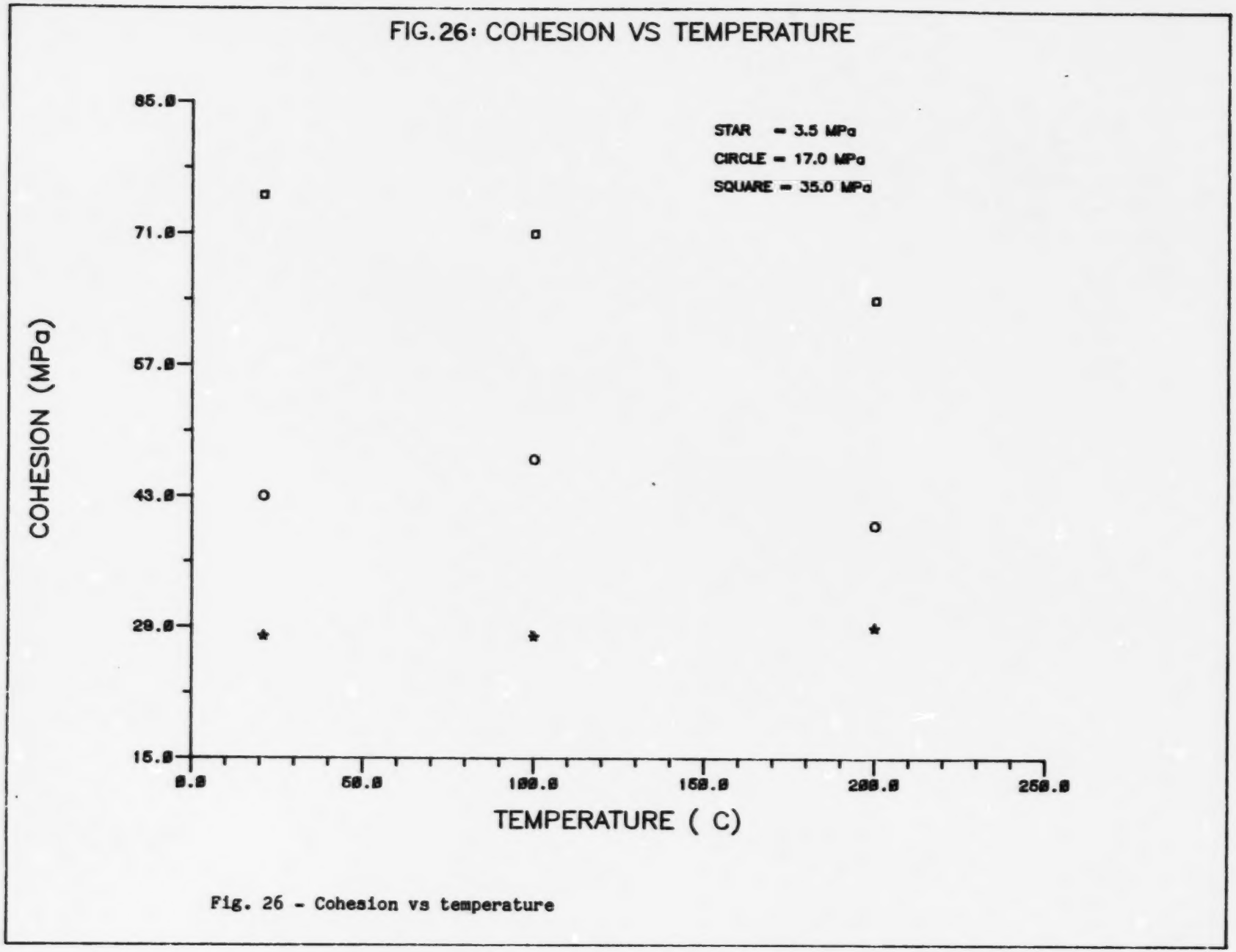

Fig. 26 - Cohesion vs temperature

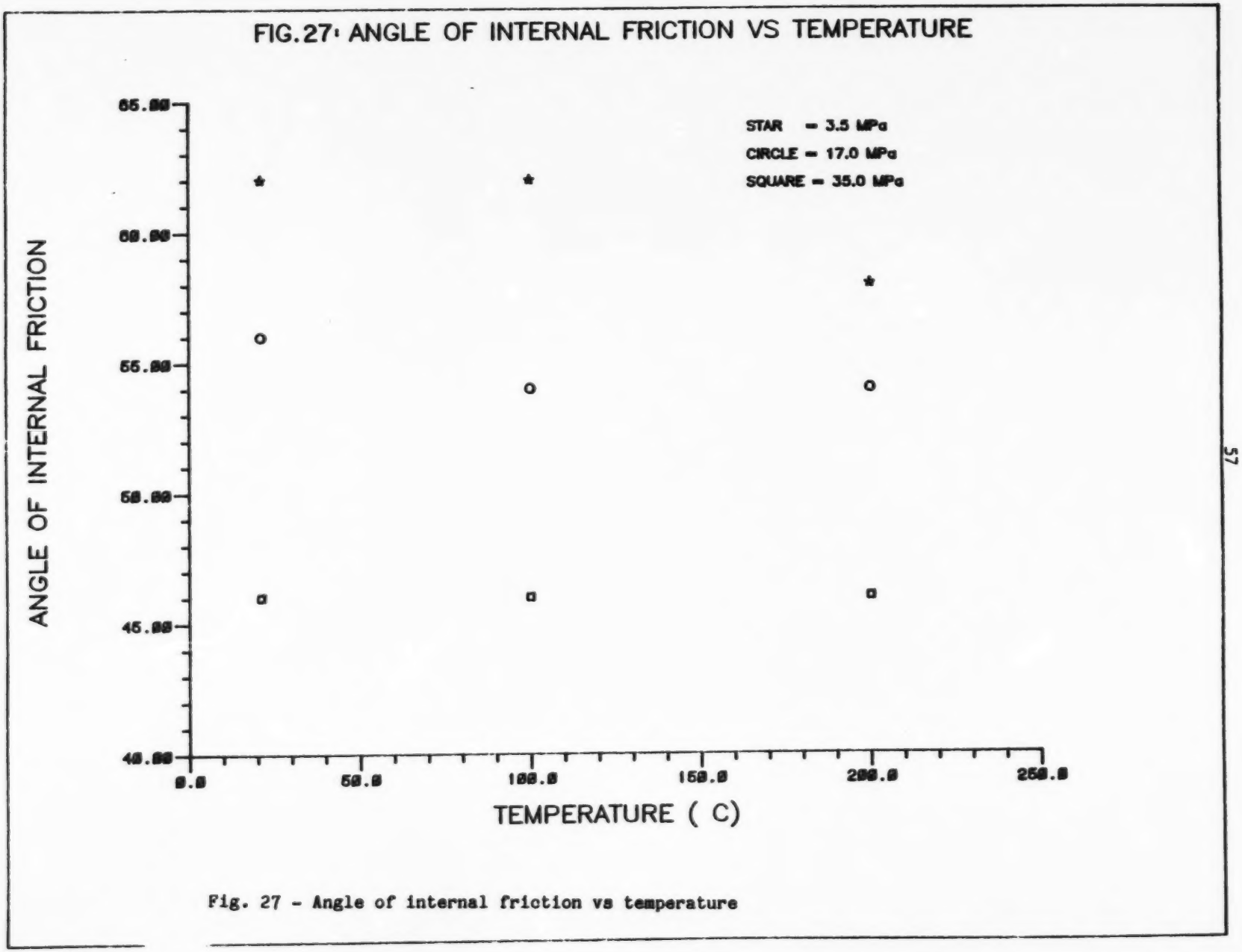

Fig. 27 - Angle of internal friction vs temperature